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# IONIZATION DETECTOR SYSTEM

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Honeywell, Incorporated

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# IONIZATION DETECTOR SYSTEM

# FINAL REPORT

BY

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W.E. Anderson

September 1973

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DEPARTMENT OF THE ARMY

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ABSTRACT


The work described in this final report covers the period from 9 June 1972 to 9 August 1973 for studies and design changes aimed at improving the Ionization Detector System overall performance capability. This report outlines the program approach, the system design changes, results of the studies and performance data for the three modified systems. The Ionization Detector System performance was improved by increased reliability, improved cells, improved calibration features, increased EMI performance and a modified inlet system. Other design changes included the use of improved 'O' rings, rotating the fuse for better access, changing to heavy duty connectors, and improvements in the design of the Surface Contamination Module ( )



4. Keywords

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## FOREWORD

The work described in this final report is authorized under U.S. Army contract no. DAAA 15-72-C-0335 entitled Ionization Detector System (unclassified) which was started in June 1972. This work is performed against USAF Project/Task 3221-02. (Chemical Agent Detection). The report covers the effort from 9 June 1972 to 9 August 1973.

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## SUMMARY

The objective of this program was to perform studies and based on these studies to make necessary system and component changes in the Ionization Detector. The studies and subsequent modifications were to correct design deficiencies revealed during testing and evaluation of existing prototypes, thereby improving the overall system performance. The major areas of improvement were directed at achieving more reliable pumps and motors, improving cells, improving the electromagnetic interference (EMI) performance of the system, understanding the radiation source degradation and improving the air sampling inlet. In addition, external panel-screw adjustments were incorporated for flow, flow compensation and alarm level adjustments; an external calibration unit was designed and fabricated; and improvements were incorporated into the surface contamination monitor. Other minor system improvements and tasks which were accomplished during the program are also presented in this report.

Major Ionization Detector improvements were these:

1. The reliability of the motor pump was improved primarily by incorporating a different motor, preloading the motor bearings, specifying a different bearing lubricant, redesigning the pump eccentric, and making improvements in the material of the valves and diaphragms. Life tests with the new motor pumps have exhibited reliable operation in excess of 6000 hours, exclusive of diaphragms, and were still running at the conclusion of the program.
2. Cells were improved by utilizing more intense (1 Ci vx. 0.25 Ci) tritium source, changing the contact material, and improving the rigidity of the baffles.
3. The sample inlet now can be more readily cleaned by removing a cover. Provisions are included for the addition of a particulate filter.
4. All necessary system changes were incorporated for the system to comply with the EMI specifications of MIL-STD-826A.
5. A radiation monitor fixture was designed and fabricated for measuring the tritium source strength and monitoring various sources with time.
6. Flow, flow compensation and alarm level adjustments can now be performed by external trim pots. Previously only the alarm level could be adjusted which required removing the top cover of the sensor module with the introduction of electrical noise.
7. Surface-contamination monitor improvements include circuit changes, the addition of a radiation shield for the temperature probe and a redesigned temperature probe.
8. A field calibration device was designed and fabricated which provides a means of checking the sensor performance, including the response of both channels and flow.

Agent sensitivity and field interference tests were conducted by Edgewood Arsenal. The detailed results are included in this report. The agent sensitivity appears to be equal to or better than that of the initial sensors (MADS, Multi-Agent Detector System). The magnitude of the cell response has been nearly doubled. The field interference tests were conducted using a variety of potential interferences. Extremely heavy concentrations of diesel exhaust and green signal smoke were the only materials which caused alarm responses.

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ILLUSTRATIONS CONTINUED

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TABLES

## IONIZATION DETECTOR SYSTEM

### I. SENSOR IMPROVEMENT STUDIES

A characteristic noted with the IDS cells had been a gradual decrease in sensitivity as a function of time. This phenomenon was observed with the MADS sensors during the 1971 Edgewood Arsenal tests during which sensitivity measurements were made before, during, and after the test series. A gradual decrease in response to similar concentrations of agent was noted. A limited investigation with several units following the Edgewood field test indicated that this characteristic may be caused by a combination of several factors. The flow rate through the cells appeared to be a critical parameter. Since most of the units did experience a flow decrease, some loss of sensitivity could be associated with the flow decrease. A film on the source surface and/or some decay of the source strength could also be factors affecting the sensitivity of the cells. To improve the overall characteristics of the cells the following areas were investigated:

- Flow decrease
- Contact material
- Source strength
- Source type and experimental cells
- Cell material and design
- "O" ring seals

#### A. Flow Decrease

It was noted that the response or signal magnitude of the I.D. cells decreases with decreasing flow. A flow compensation network had been incorporated into the MADS design. By combining the signal of a flow sensing cell with the agent sensing cell, variations in flow rate were compensated. However, some deficiencies of this scheme existed. The network worked well in the laboratory under controlled conditions, but long-term decreases in flow rate were not fully compensated under field conditions. This problem had been very critical since the loss in flow rate over extended periods occurred primarily due to increased drag torque with bearing failures.

The lack of long-term flow compensation was thought to be due to several factors. A decrease in the ionization efficiency of the flow cell or a mismatch in the cell characteristics could both be causes. Also some variation of compensation required between units had been noted which was due to variations in individual cell sensitivity. A block diagram of the flow compensation network is shown in figure 1.

An investigation of the flow compensation network was made. The characteristics of two different IDS units are shown in figures 2 and 3. The two figures illustrate that a large difference exists in the flow compensation characteristics between the two units. With the sensor shown in figure 2, the compensation is adequate, while that illustrated in figure 3 had a decreasing slope of the response curve with decreasing flow. This indicates that due to

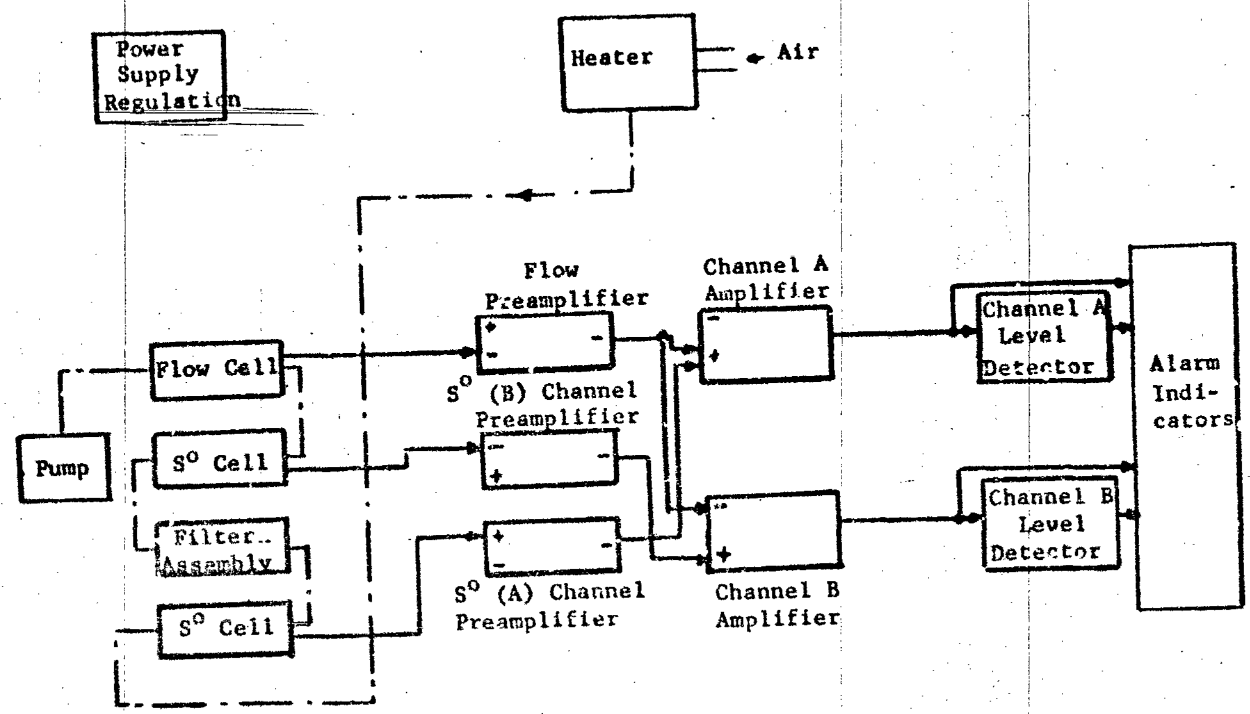



Figure 1. Block Diagram of IDS Flow Compensation Network

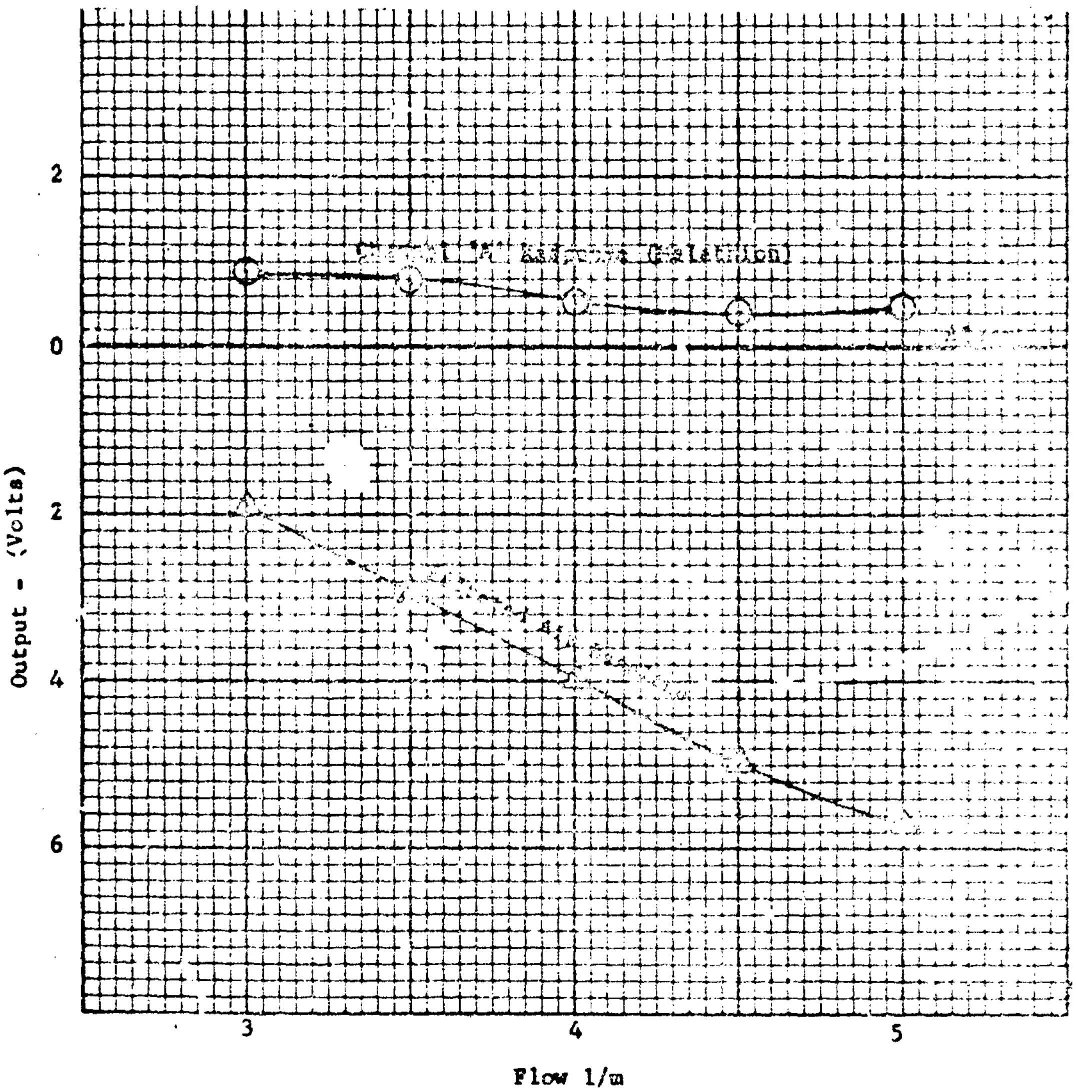



Figure 2. Flow Compensation Unit #9

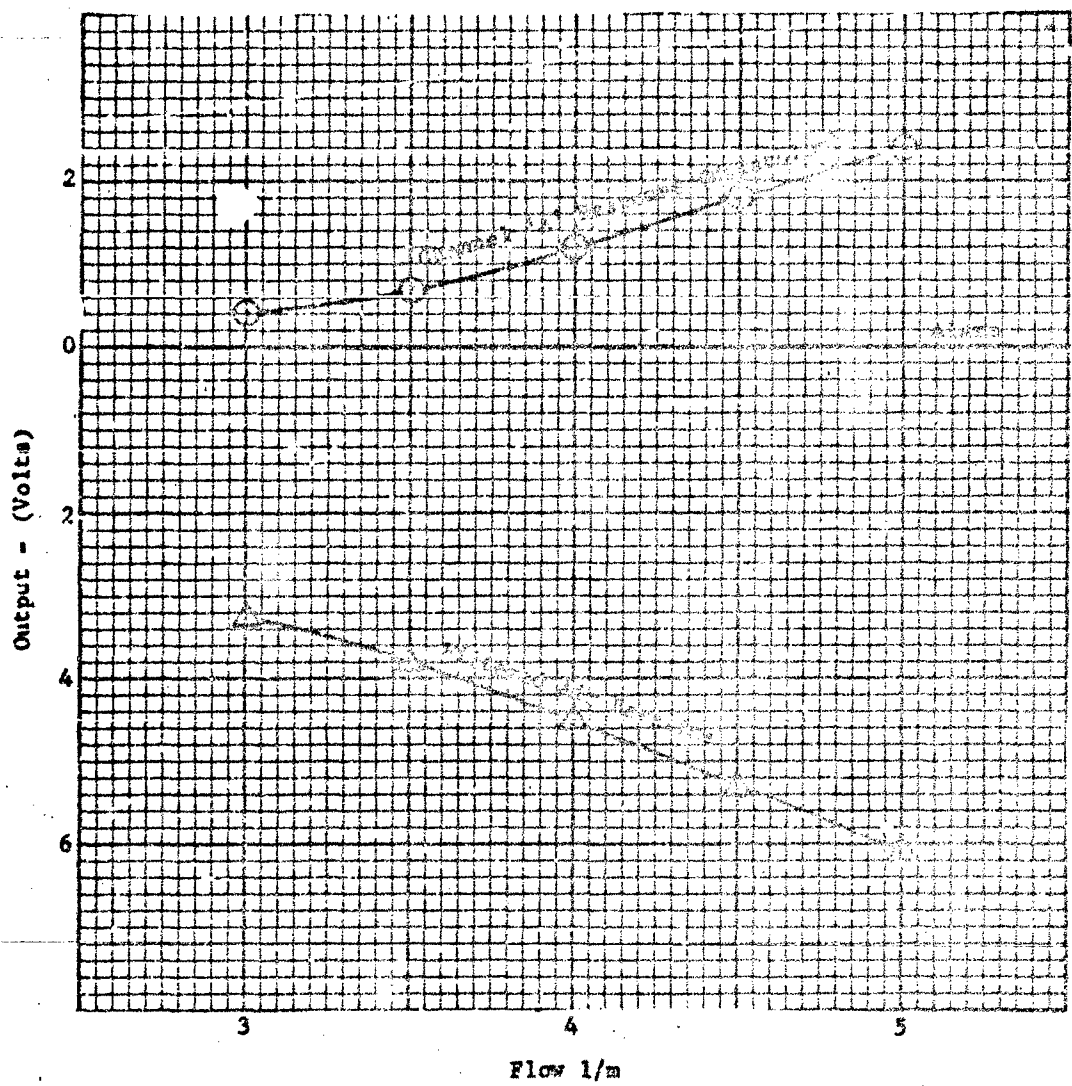



Figure 3. Flow Compensation Unit #12

the difference of individual cell characteristics, matching of the flow compensation network with the individual cell characteristics was required. Figure 4 illustrates the same sensor shown in figure 3, but with the flow compensation network more nearly matched to the cell characteristics. The examples shown display a large flow variation of two liters per minute; with improvements in the pump, flow variations should be less then 1/2 normal liter per minute (nℓ/m).

During the November agent tests, experiments were conducted varying the flow rate of the detector and recording the sensor output to a fixed concentration of agent. At 3, 4 and 5 nℓ/m the unit was exposed to both agents 'VX' and 'GB'. The results are illustrated in figures 5 and 6.

To improve the characteristics of the flow compensation network several design improvements were made. This included the addition of a separate flow compensation adjustment and a alarm level adjustment, and improvements in the flow cell characteristics.

As noted in figure 1, the flow/compensation network takes the output of the flow cell, inverts this signal and adds it to the output of the $S^0$ cell. The amount of compensation provided by the flow cell can be adjusted with a potentiometer. This adjustment changes the slope of the flow cell output curve. However, proper adjustment of the flow compensation does not necessarily result in the proper alarm level. By adding an adjustable bias to the flow cell output, the alarm level can then be adjusted without affecting the slope of the flow compensation curve. This feature was added to the modified units as an external adjustment. Features of the external flow compensation and alarm level adjustments modification are outlined in section III.

A characteristic noted of the IDS cells is that the slope of the response curve with varying flow changes with various concentrations. With the type of flow compensation scheme used in the IDS units, ideal correction for changes in flow can therefore only be accomplished over a limited range of concentration. This characteristic is illustrated using a simulant. Figure 7 illustrates the responses of the modified sensor to various concentrations of dipropylamine for flow rates from 3 to 5 nℓ/m. Note for 160 ppm of dipropylamine the sensor flow compensation is adequate while the response curve to higher concentration is not properly flow compensated.

To decrease the effect of this phenomena, the flow compensation is adjusted for flat response curve with threshold concentrations of agent. At these concentrations flow compensation is the most critical. For higher concentrations the response curve is well above the alarm level and small decreases in response due to flow changes will not effect the alarm.

Improvements in the motor pump will also decrease the effect of decreasing flow. Motor pump improvements are outlined in more detail in Section VII.

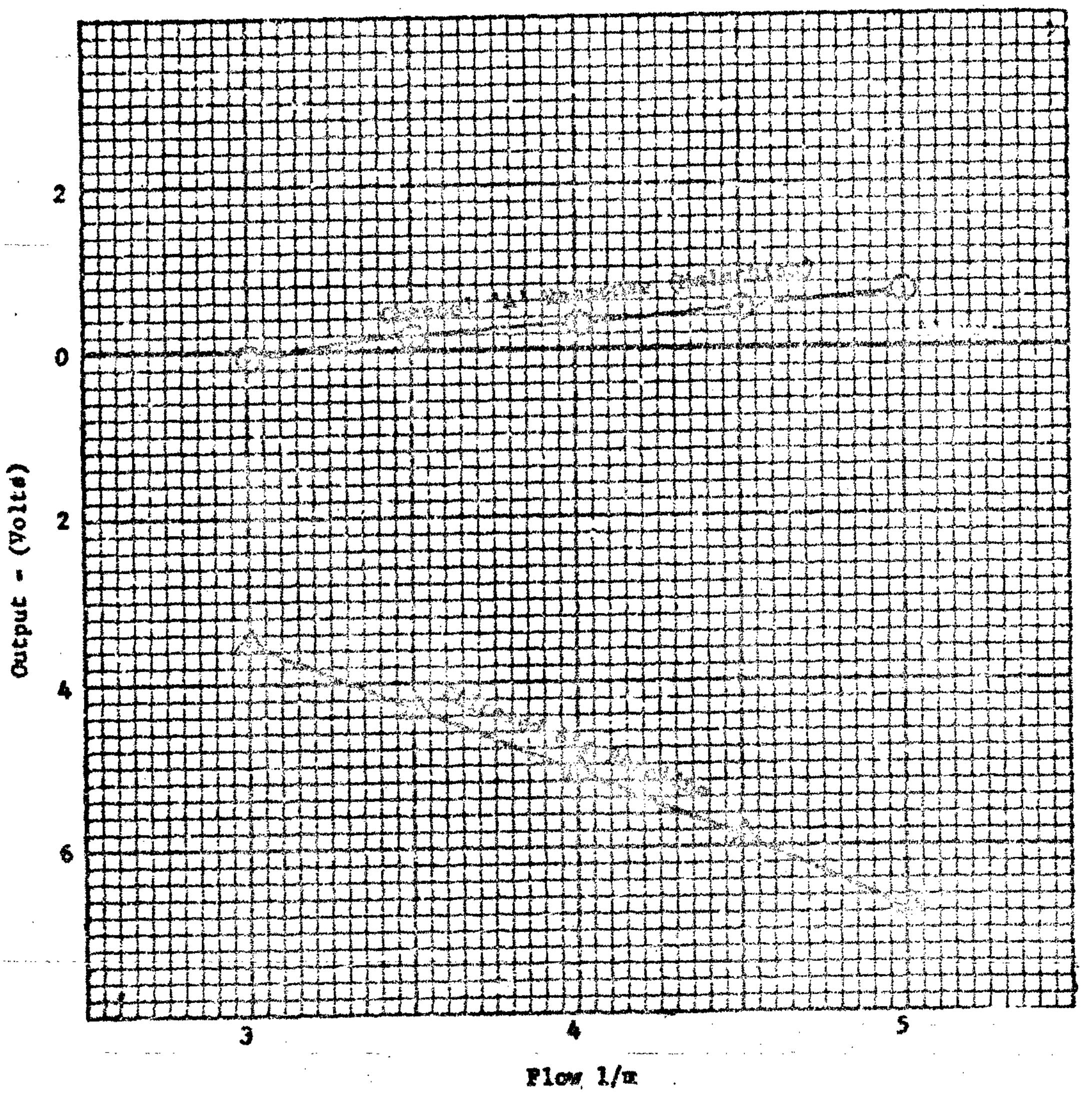



Figure 4. Flow Compensation Unit #12

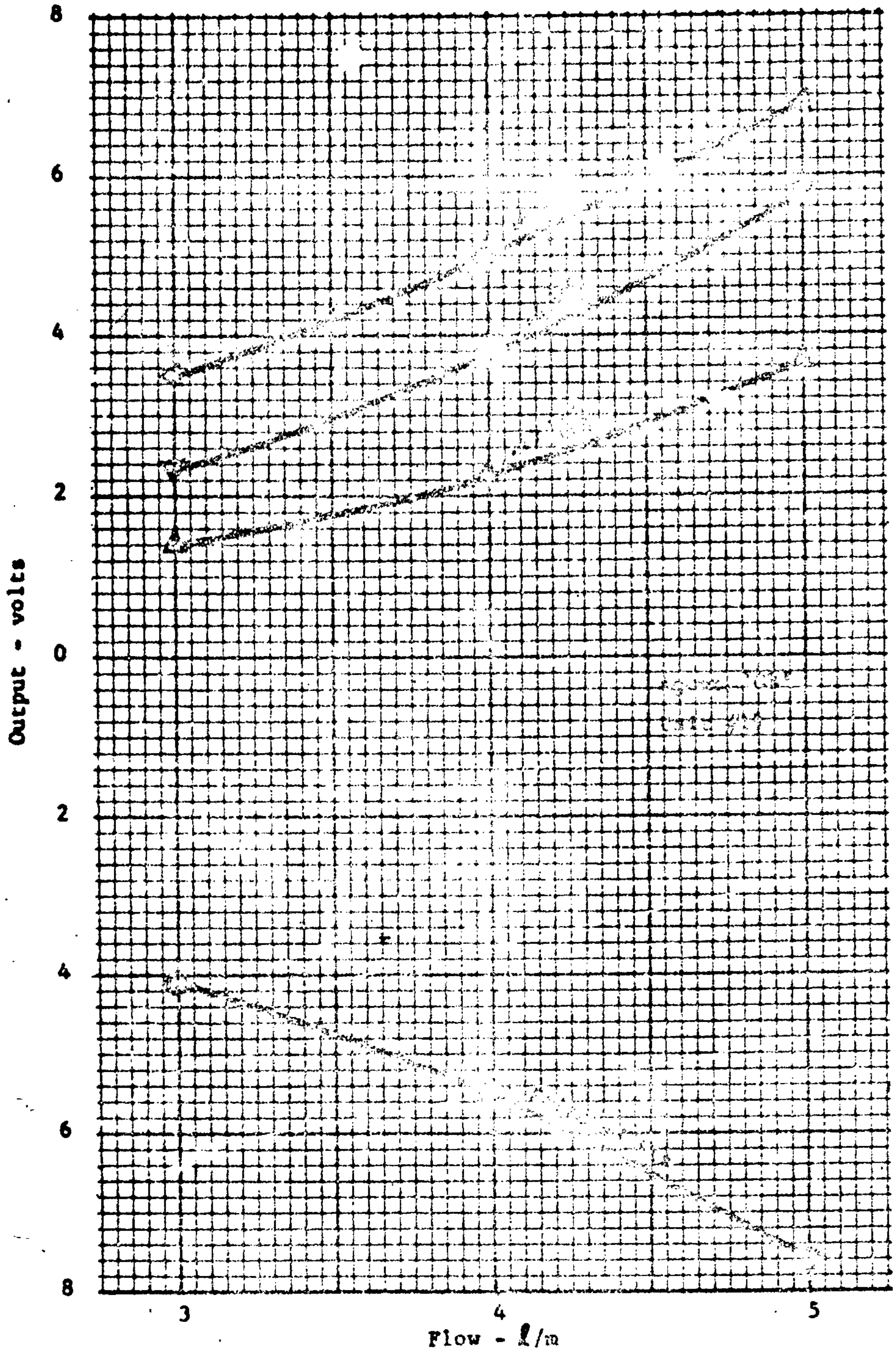



Figure 5. Response As A Function Of Flow

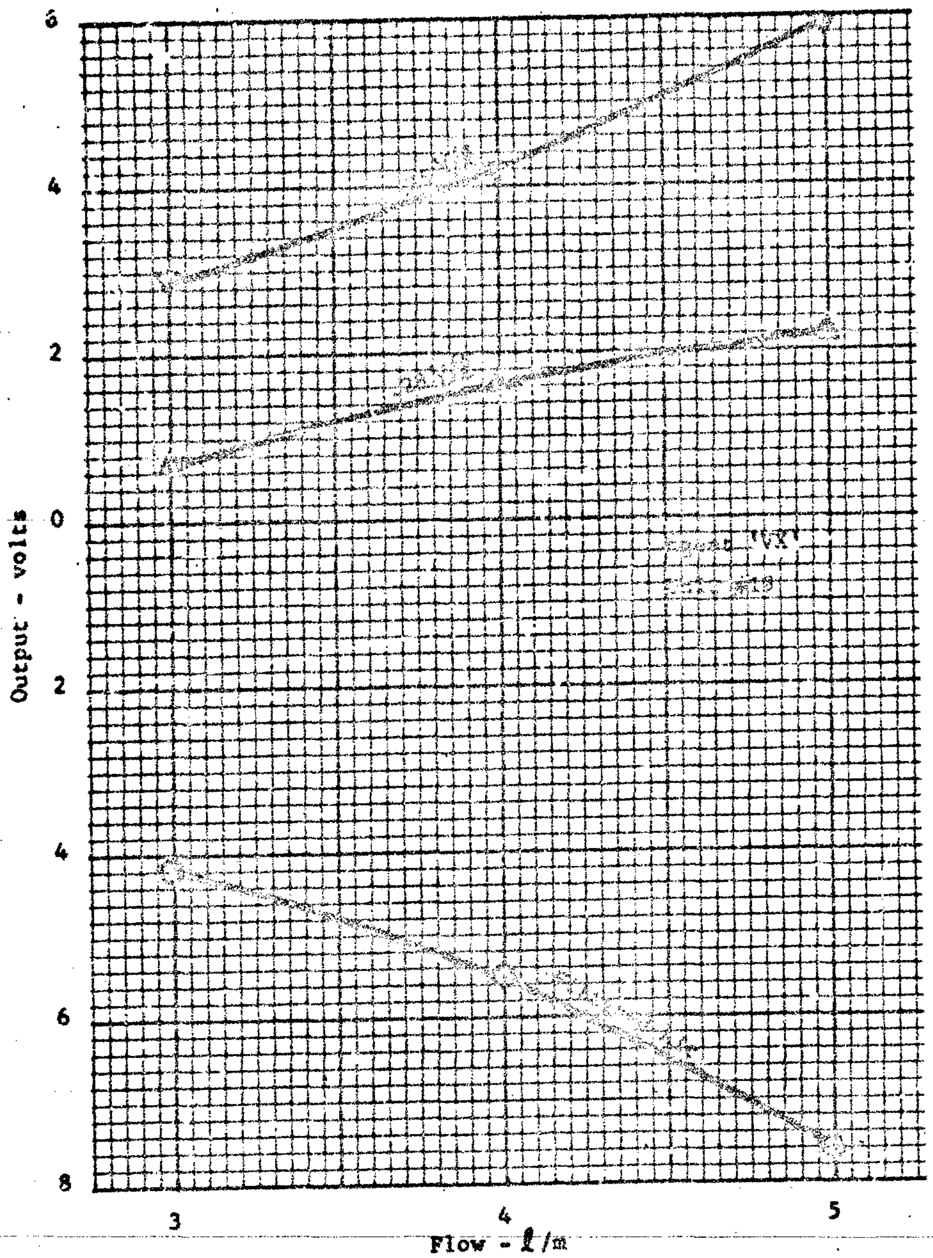



Figure 6. Response As A Function of Flow

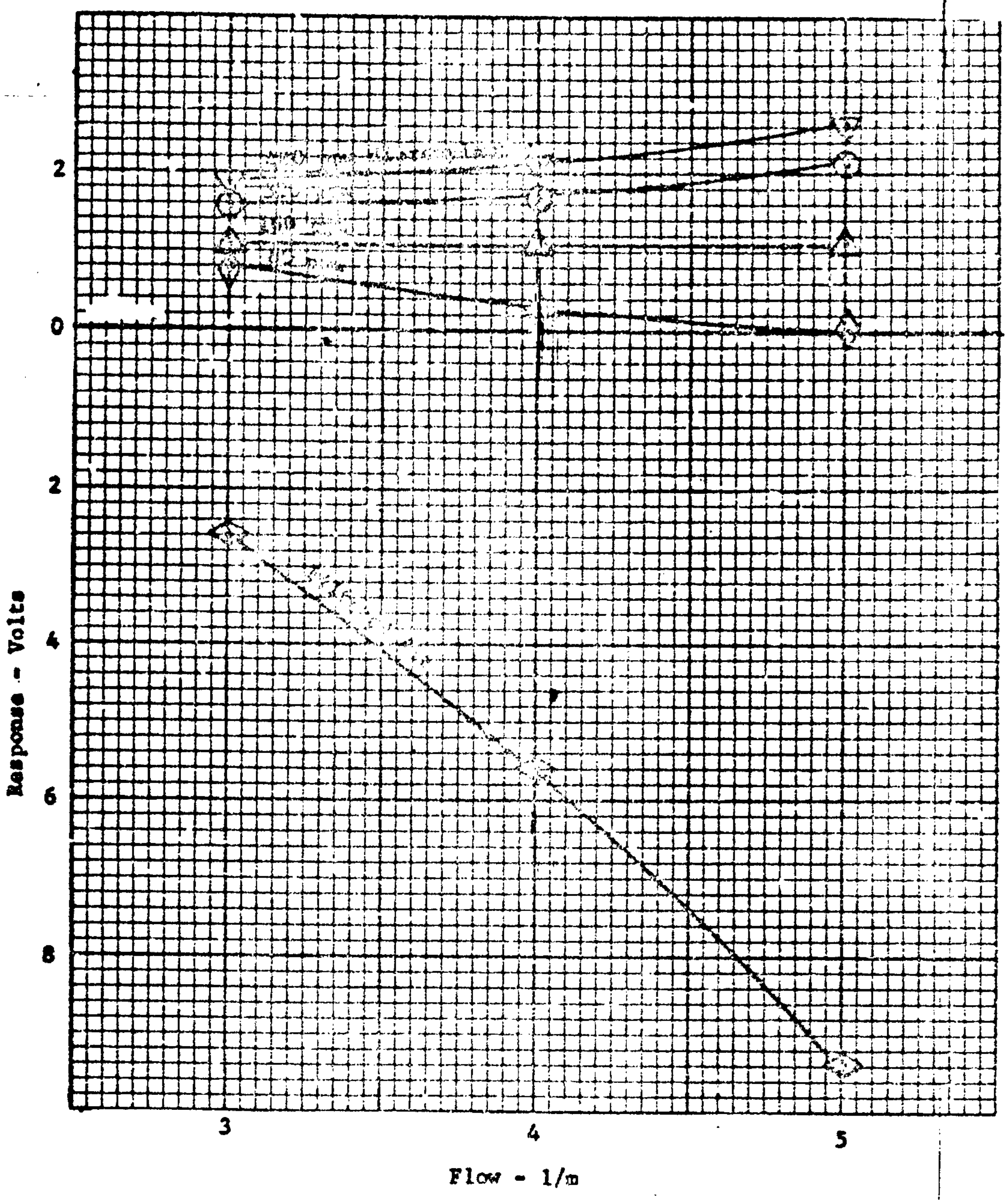



Figure 7. Modified Sensor Response versus Flow

To improve the linearity of the flow compensation network the characteristics of the flow cell were examined. The response characteristic (filtered air) of the MADS flow cell with varying flow is illustrated by the lower curve of figure 8. To improve the linearity of the flow cell response a different design for the flow cell was examined. The design of this cell is illustrated in figure 9 and the response characteristic, shown by the upper curve of figure 8. As noted by this illustration the linearity of the new flow cell has been improved over the range of flows shown. The response curve of an IDS (sensor cell) is not completely linear, but over a limited flow range of approximately one liter, the combination of the two cells approaches a straight line. The new type flow cells were incorporated into the three modified units.

B. Contact Material

To make electrical contact between the cell and terminals, a wire-type spring is used at one end of the cell while a wave washer is used at the opposite end. This design is illustrated in figure 10. With this type of configuration, the cells can be interchanged without much effort and the cell can be fabricated independently of the cell holder. To decrease the contact resistance and potential and eliminate long-term changes in the contact resistance and potential, nickel-gold-plated contacts were tested. Nickel-gold plating has a low contact resistance and is not subject to oxidization. A tin-plated contact had been used which appears to oxidize seriously with usage. Since the current associated with the cell is very small, any change in contact resistance and potential could alter the sensor performance. The nickel-gold-plating has been applied to both pressure contacts and to the surfaces which make contact with the spring and washer. This modification has been incorporated into all three modified IDS units.

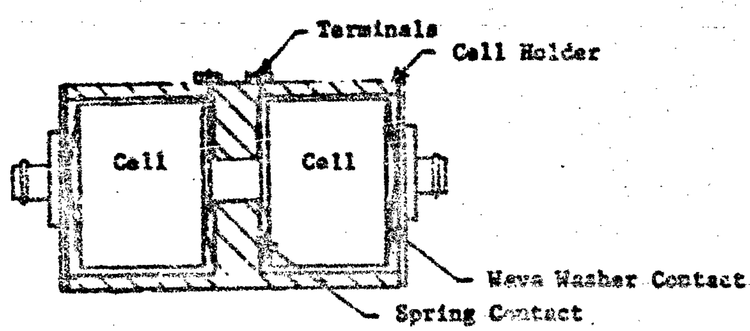



Figure 10. Cell Holder and Contacts

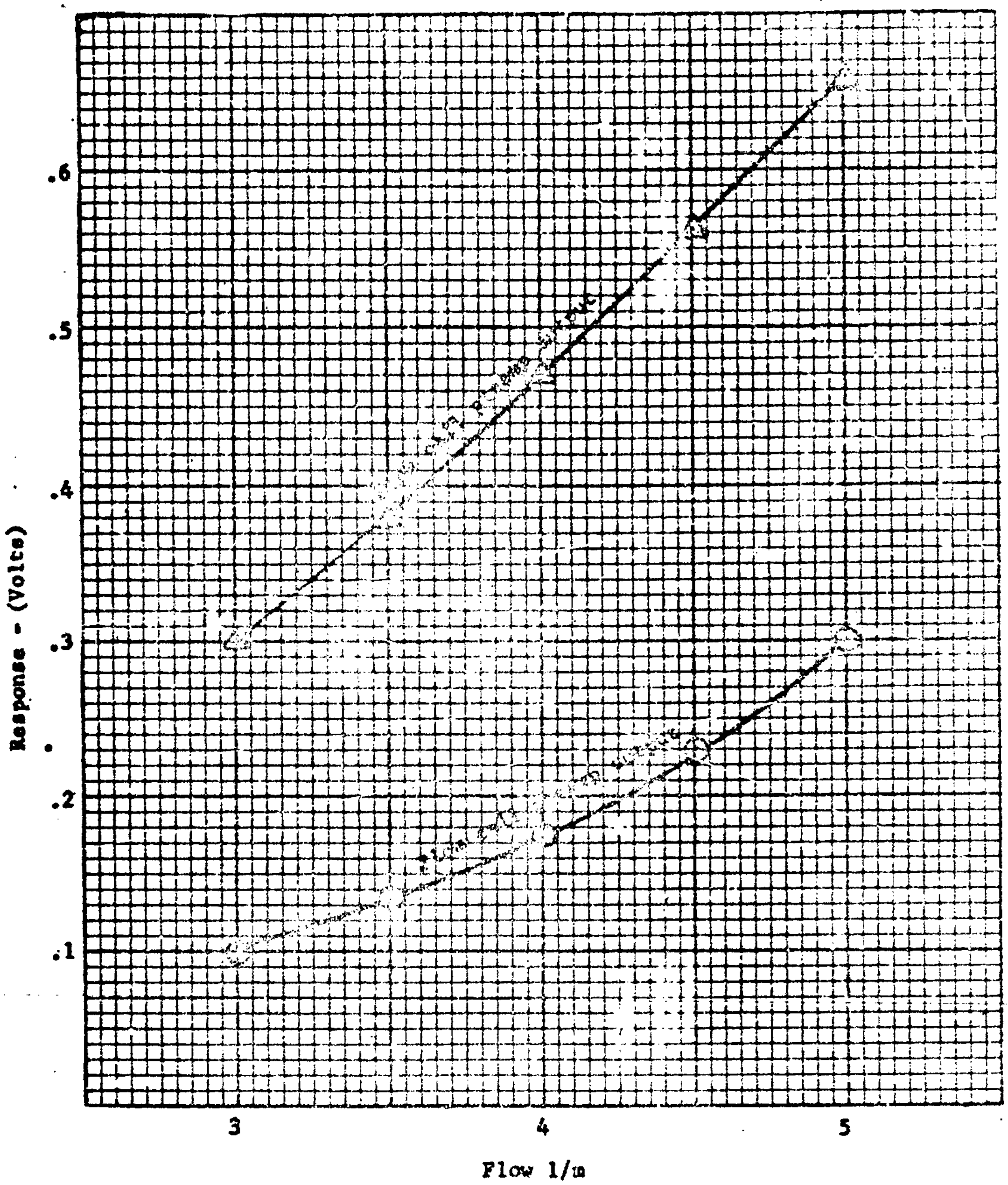



Figure 8. Flow Cell Comparison

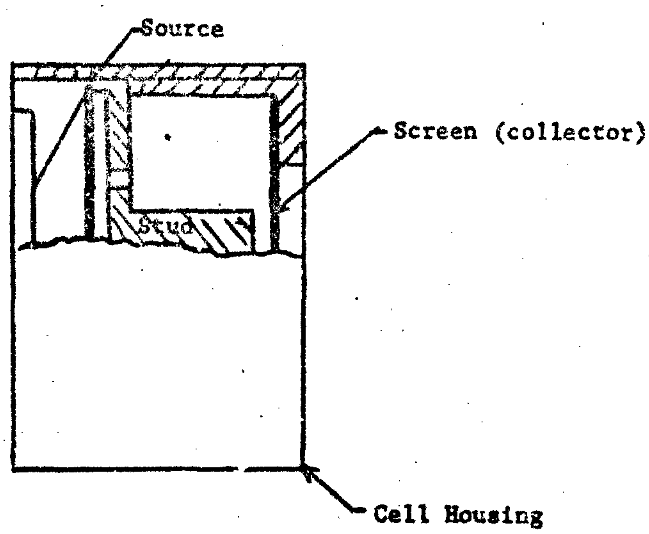



Figure 9. Modified Flow Cell Design

C. Source Strength

Efforts to minimize long-term sensitivity decay resulted in an investigation of the ionization source. Decreases in ionization current could be due to loss of the tritium or to films such as grease or dirt. Losses of tritium would affect the ionization current to a large extent. Figure 11 shows the current output of titanium tritide foils. The MADS cell incorporated a 1/2" x 1/2" source with a tritium concentration of 1 $Ci/in^2$ for a source strength of 250 mCi per cell. As noted from figure 11 this is in a steep portion of the curve and any small loss in source would have a large effect on the ionization current. Small amounts of dirt or other films on the surface would also result in large decreases. Cells utilizing sources with 4 $Ci/in^2$ or 1 Ci per cell were fabricated and have been tested in the IDS. Operating in the flat portion of the ionization curve should result in smaller long-term decreases in ionization current. The use of the larger sources was incorporated into the three modified IDS modules.

These sources are fastened to the screen with a conductive epoxy as compared to the previous spot welding technique. Welding of the sources is a questionable process due to the release of some radioactive material during welding. The epoxy appears to be satisfactory and the bond has proved satisfactory.

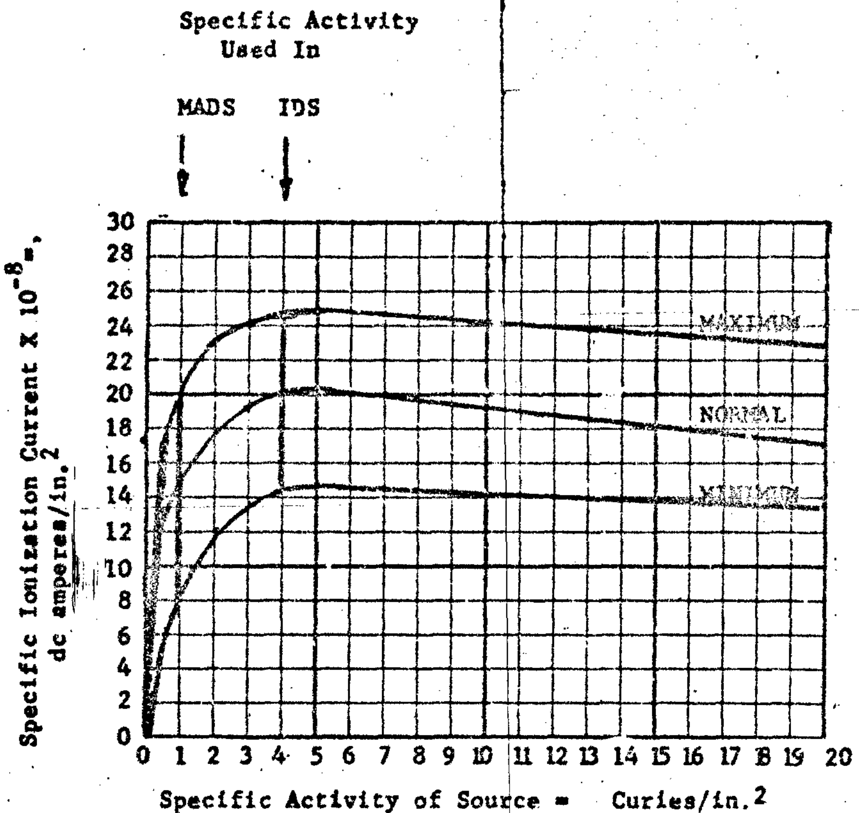
D. Source Type and Experimental Cells

Experimental cells using both americium-241 and nickel-63 were fabricated and subjected to limited tests. The nickel-63 source strength used for this cell was quite small, being approximately 15 millicuries. The magnitude of the signal was therefore much smaller in comparison to a larger tritium source. The source was available from a previous program. The americium source had a strength of 500 millicuries.

Figure 12 shows the results of these qualitative tests with americium. These responses are compared to a standard tritium cell. As noted from the data several of the chemicals tested did give different response data. The $CHCl_3$ response is much larger with the americium and both the propyl alcohol and the methyl alcohol responses are different.

Figure 13 compares the response of a nickel-63 cell with tritium. Other than the magnitude of the signal being different which is due to source size, little difference could be noted in response characteristics. The $CHCl_3$ response is slightly larger.

Figure 14 shows the agent responses of the cell containing an americium source while figure 15 illustrates the agent characteristics of the cell containing nickel-63. The cell containing the americium source did not have very large responses to agents. This cell may not have an optimum source spacing in its present configuration. The spacing in this particular experimental cell




TITANIUM TRITIDE FOILS

1. Ionization Current Range measured with parallel plate chamber at varying tritium concentrations per unit area.
2. Titanium -- tritium ratios $TiH^3_{1.00}$ -- $TiH^3_{1.73}$

Figure 11. Specific Ionization Current vs. Specific Activity for Titanium Tritide Foils (From U.S. Radium Literature.)

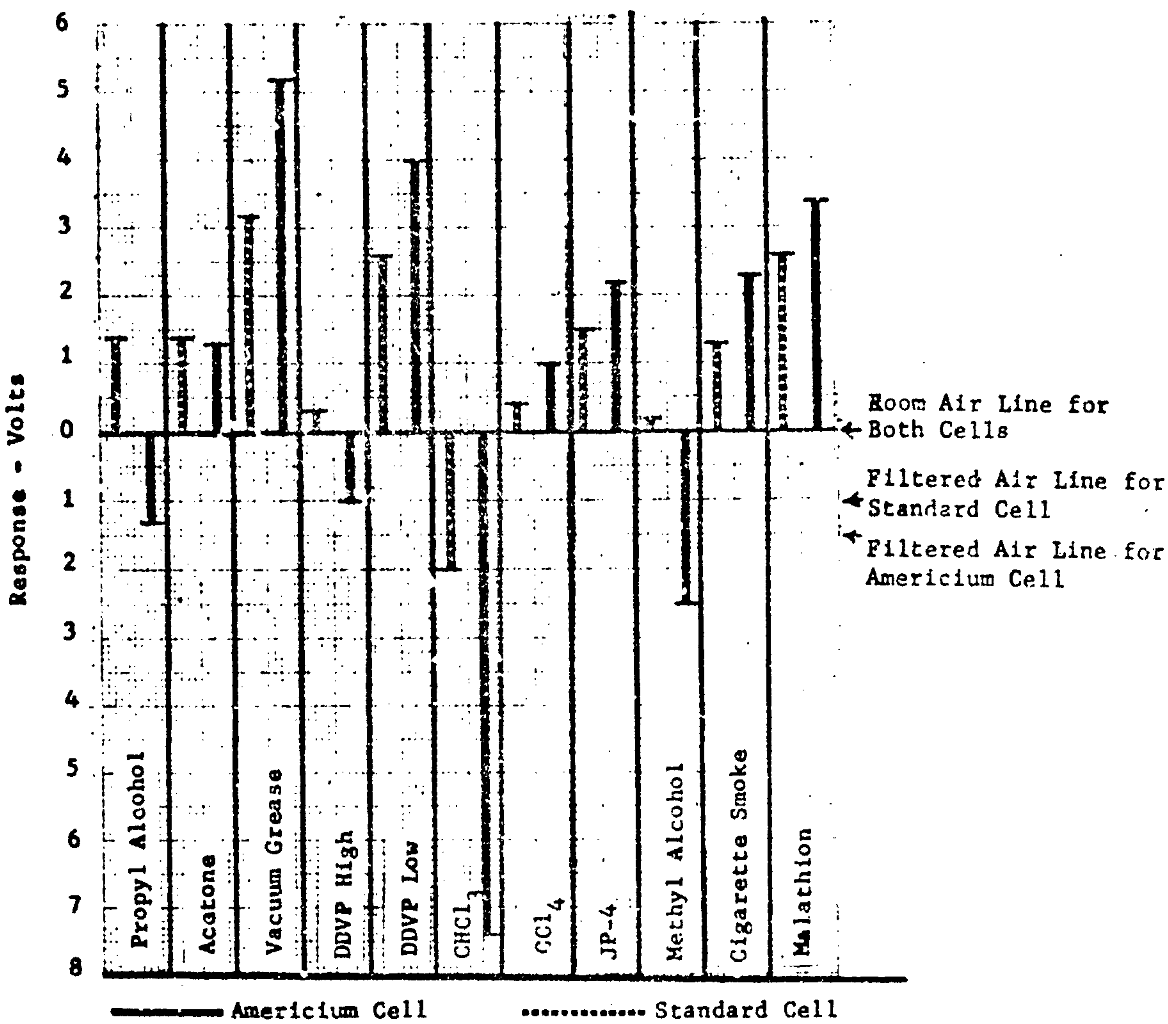



Figure 12. Response of Experimental Cell Containing an Americium Source Compared with a Standard IDS Cell

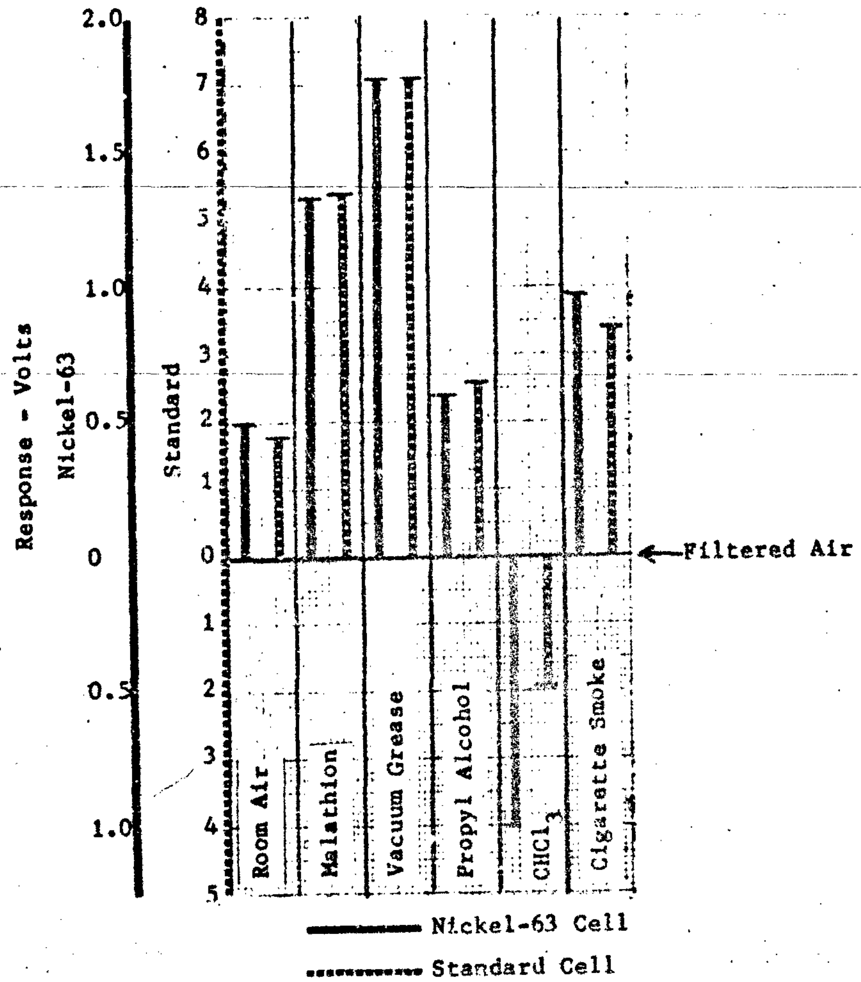



Figure 13. Response of Experimental Cell Containing a Nickel-63 Source Compared with a Standard IDS Cell

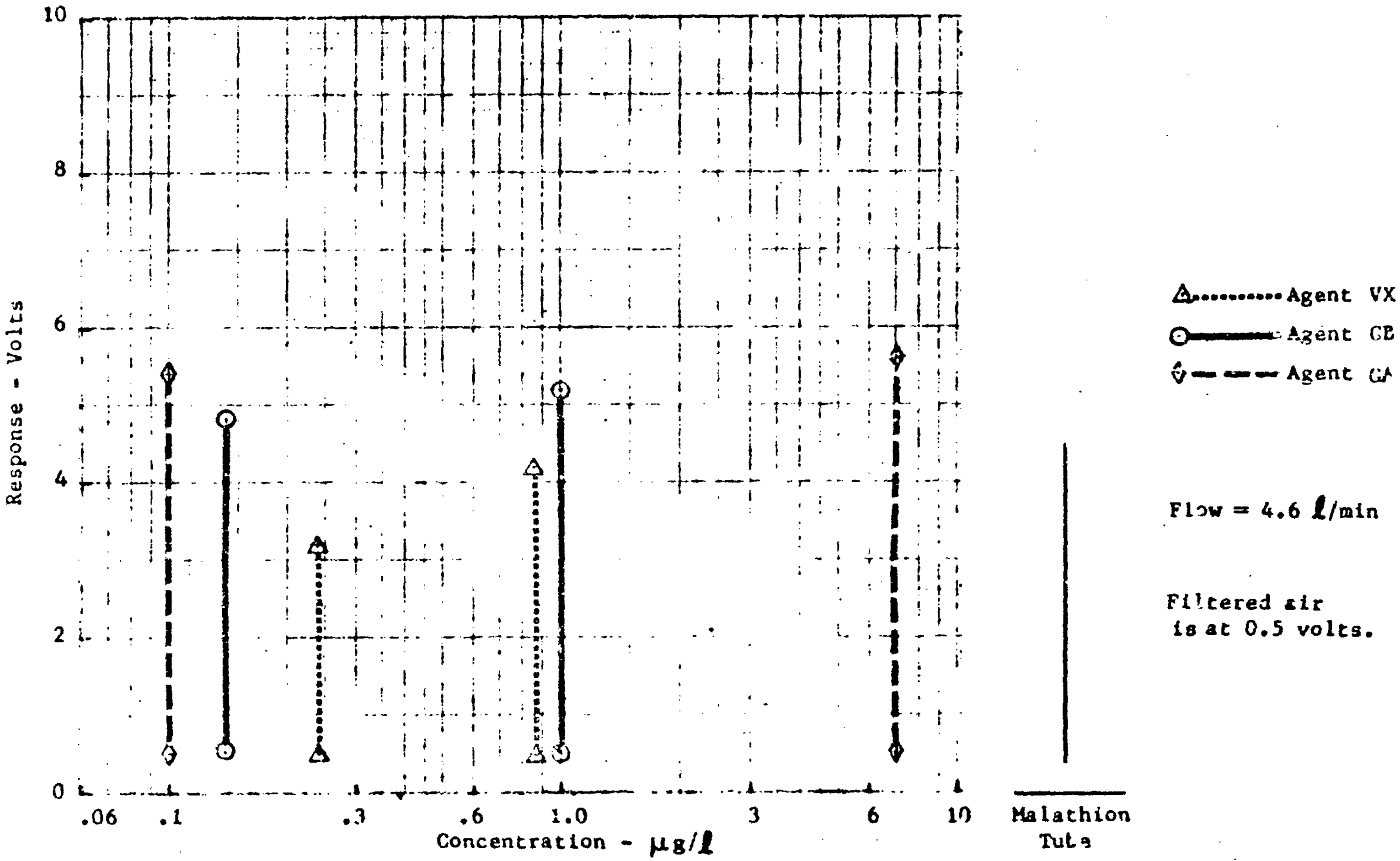



Figure 14. Agent Response of Experimental Cell Containing an Americium Source

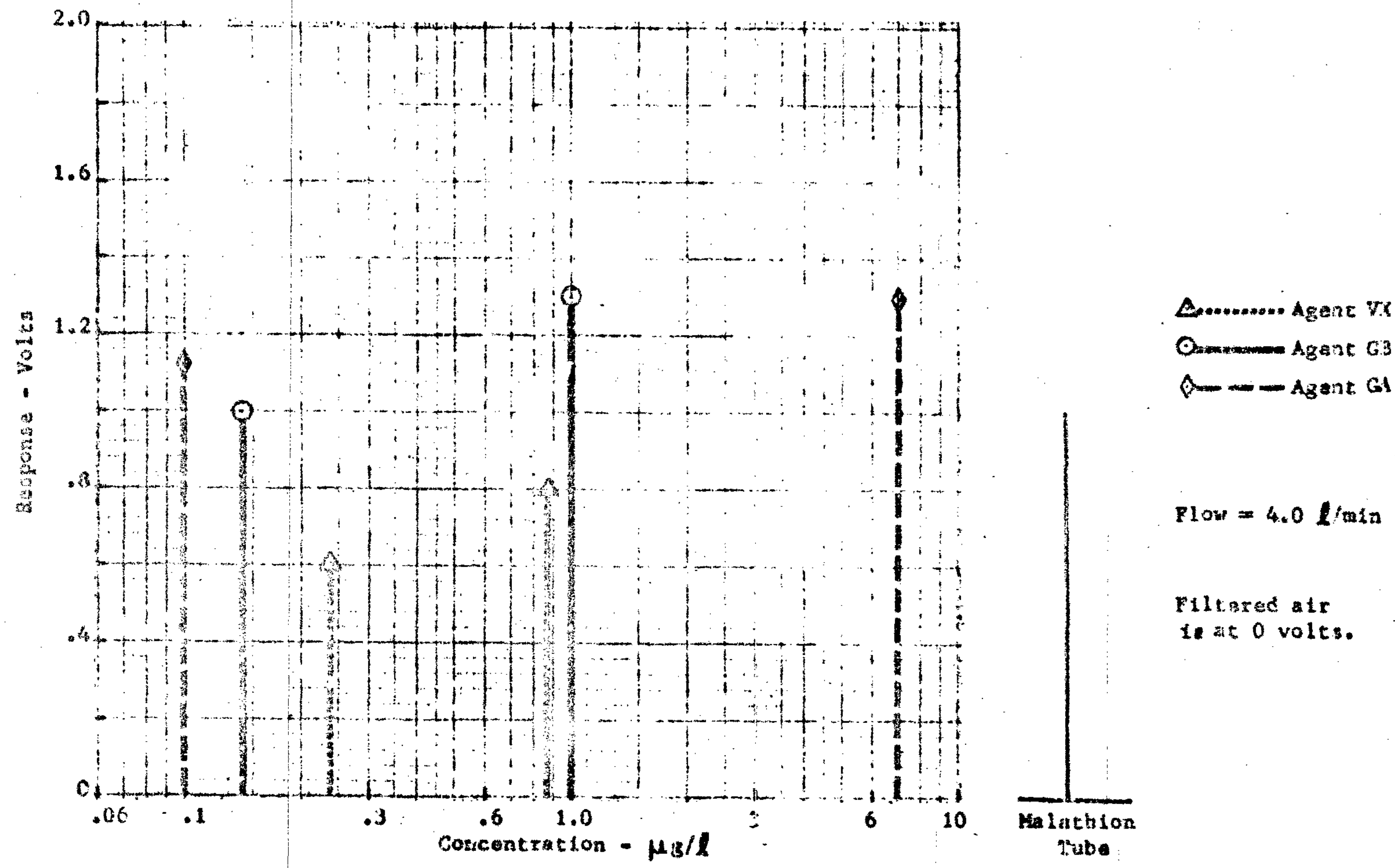



Figure 15. Agent Response of Experimental Cell
Containing a Nickel-63 Source

was 0.20 inch. The magnitude of the agent responses with the cell containing nickel-63 were comparatively small. This was primarily due to the small source size (15 millicuries). Comparative responses to other chemical vapors indicate that the nickel-63 source and the tritium source produce similar responses. This would indicate that a larger nickel-63 source could be substituted for the tritium.

To determine the effect of an altered electric field within the flow path of an IDS cell, several experimental cells were fabricated. Most of the experimental cell parameters are similar to a standard S° cell. The modified IDS cell construction is illustrated in figure 15a. The electric field is applied to the cell by substituting one of the Teflon-coated washers or baffles with one made of metal. A wire is then attached to the metal washer. The wire is made accessible whereby a voltage can be applied to the washer or baffle. One of the experimental cells was fabricated with standard IDS cell parts and only one metal washer substituted (E-1). A second experimental cell was constructed having a metal baffle in place of the conventional teflon-coated baffle and with a teflon manifold substituted for the standard metal manifold (E-2).

The second cell (E-2) was used to record the response characteristics with various voltage combinations applied to the washer (grid) and to the source. These results are displayed in figures 16-18. The voltage combinations used are noted on the graphs. The dashed lines show the response of a standard IDS unit for comparison. These tests were conducted with a dual inlet whereby both detectors were exposed to similar concentrations. The tests were qualitative-type experiments. The figures show that the response characteristics can be altered by this type of configuration.

As a result of these tests, agent tests were conducted with two of these experimental cells having grids and with the most promising voltage combinations. The agent responses of the E-1 cell were recorded with both the source (S°) and grid grounded. The cell response to three different agents at several different concentrations is illustrated in figure 19. Agent tests with the E-2 cell were conducted with the source grounded (S°) and the grid at plus nine volts. These cell responses to agents are shown in figure 20. For comparison the response to a small concentration of malathion (laboratory test standard) is also shown on the figures.

During this same agent test series, a standard IDS unit (channel A) with the latest cell modifications was also tested. These sensor responses are illustrated in figure 21. A comparison of these responses with the responses of the experimental cells shows fairly similar results. However, as previously noted the response to some other chemicals can be changed by altering the electric field within the cell. This approach could therefore possibly be a method to suppress some of the interferences. However, a program to determine all the characteristics of these cells would require considerable effort.

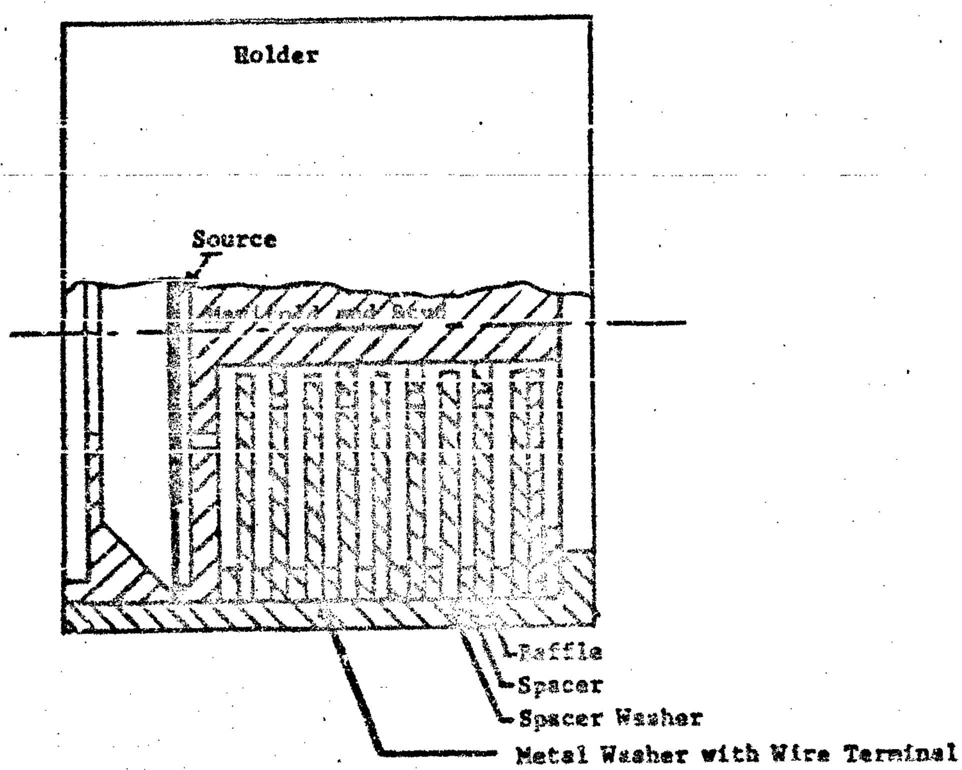
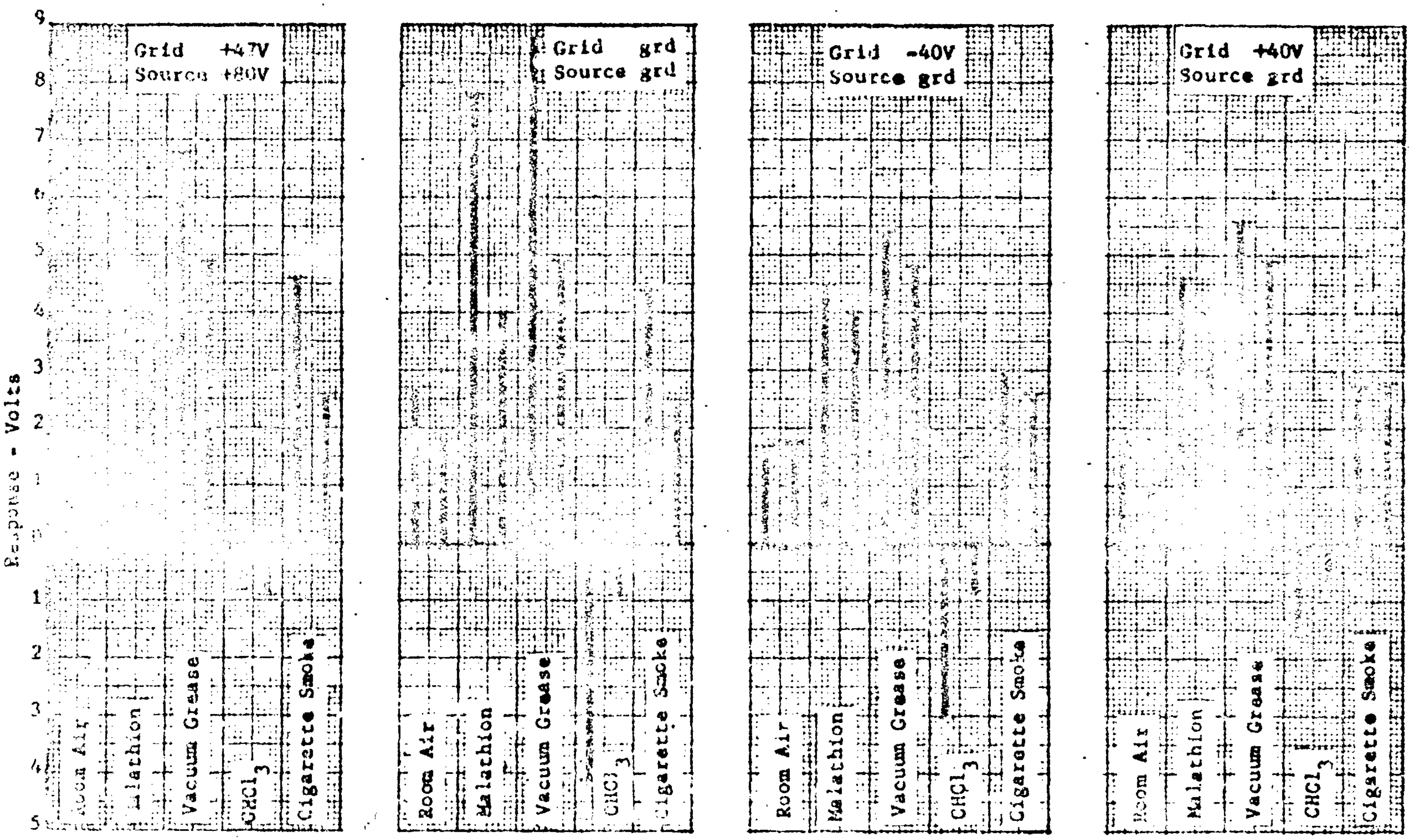



Figure 15a. Modified IDS Cell Construction




Filtered air = 0 volts — Experimental Cell ····· Standard Cell

Figure 16. Response of Experimental Cells versus Standard IDS Cells

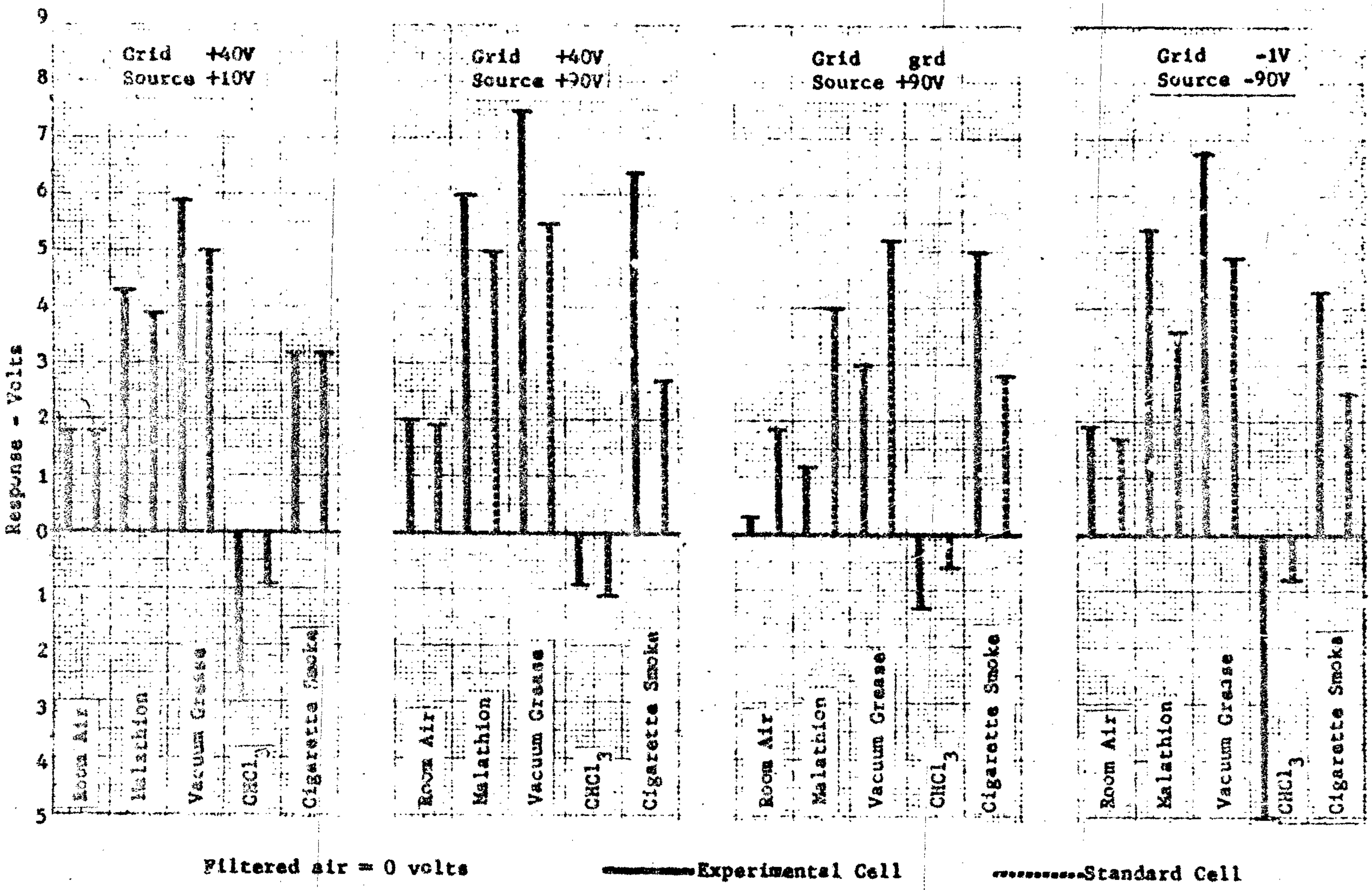
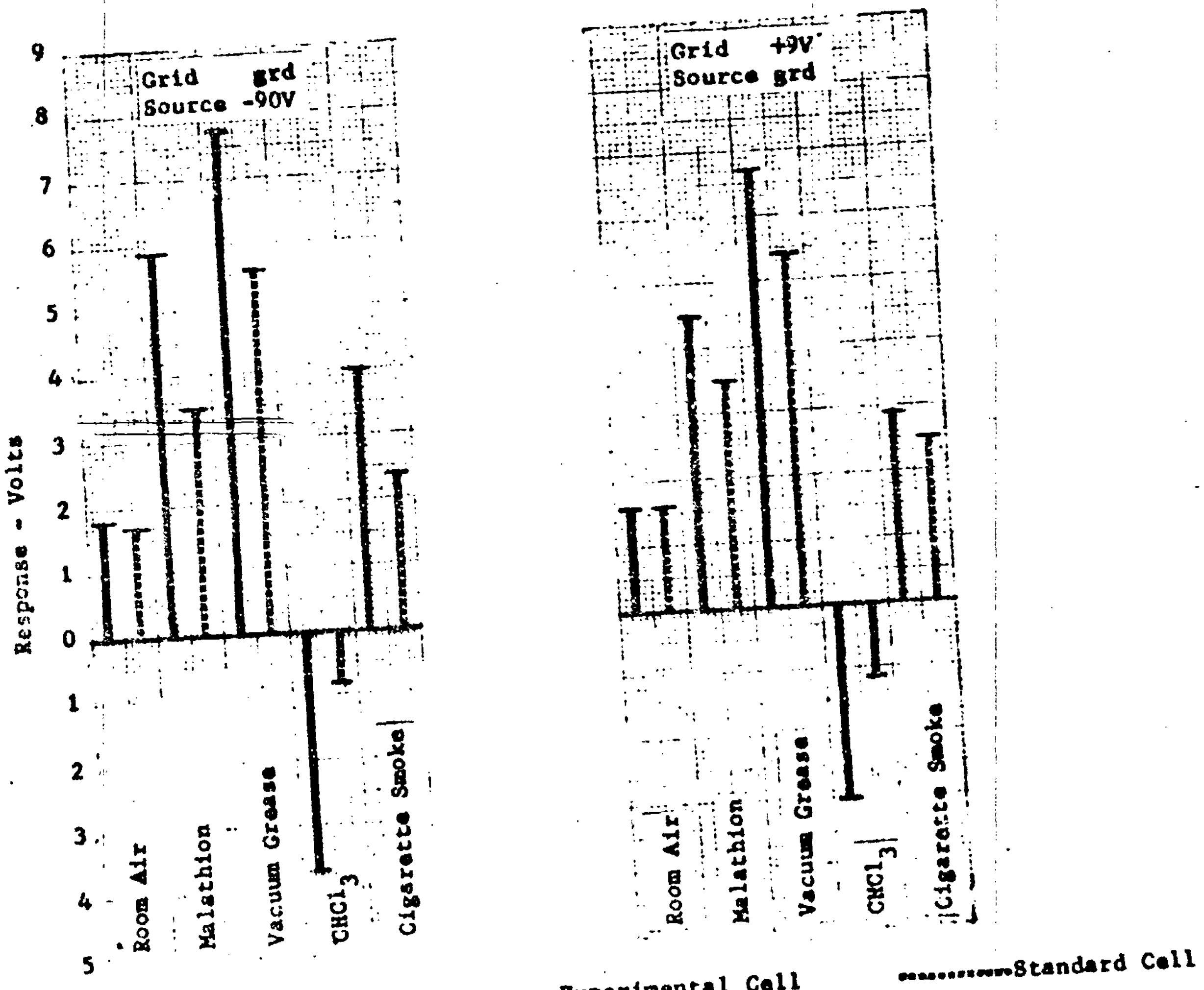



Figure 17. Response of Experimental Cells versus Standard IDS Cells




Filtered air = 0 volts.

Figure 18. Response of Experimental Cells versus Standard IDS Cells

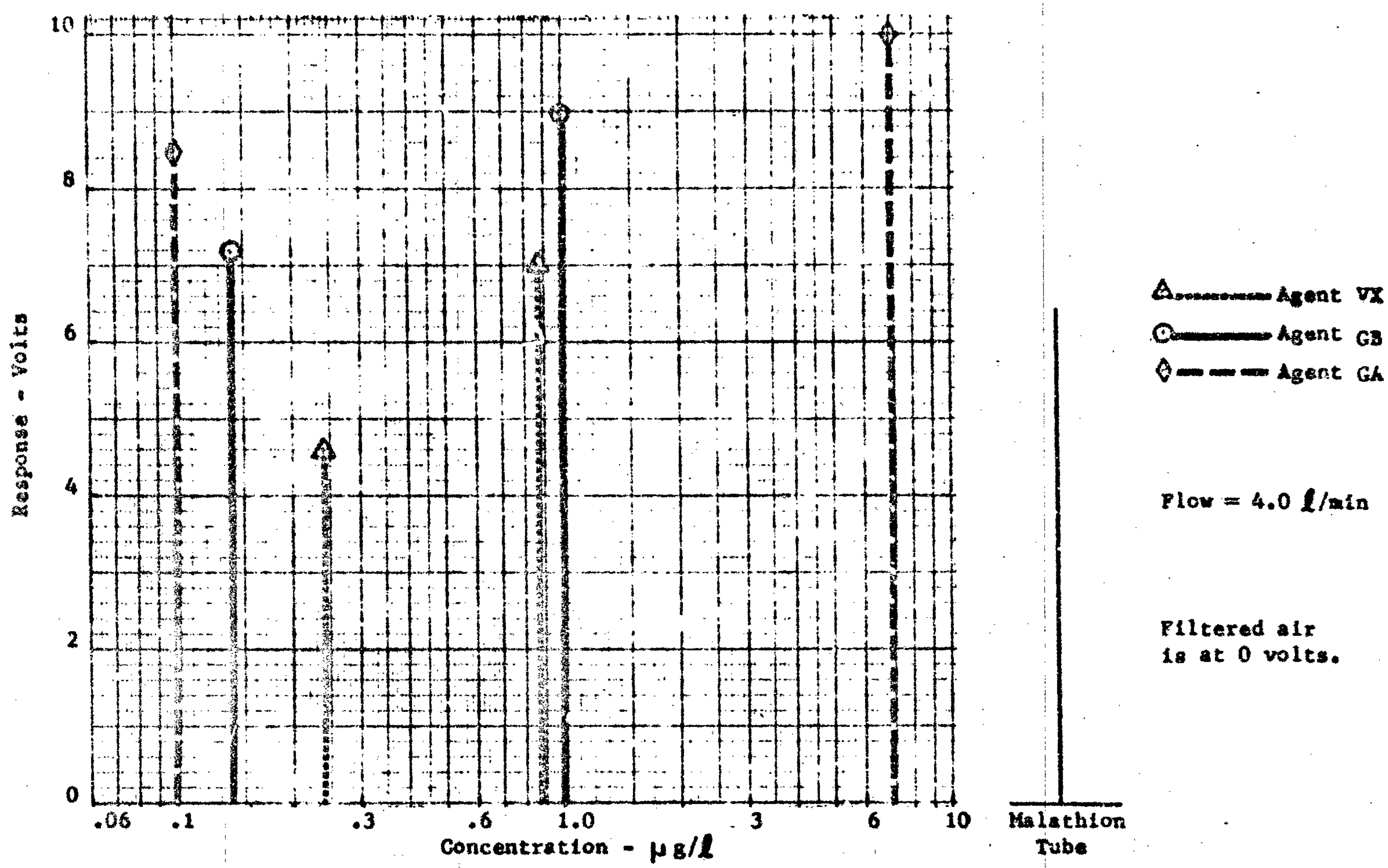



Figure 19. Agent Response of Experimental Cell E-1 with Grid Grounded

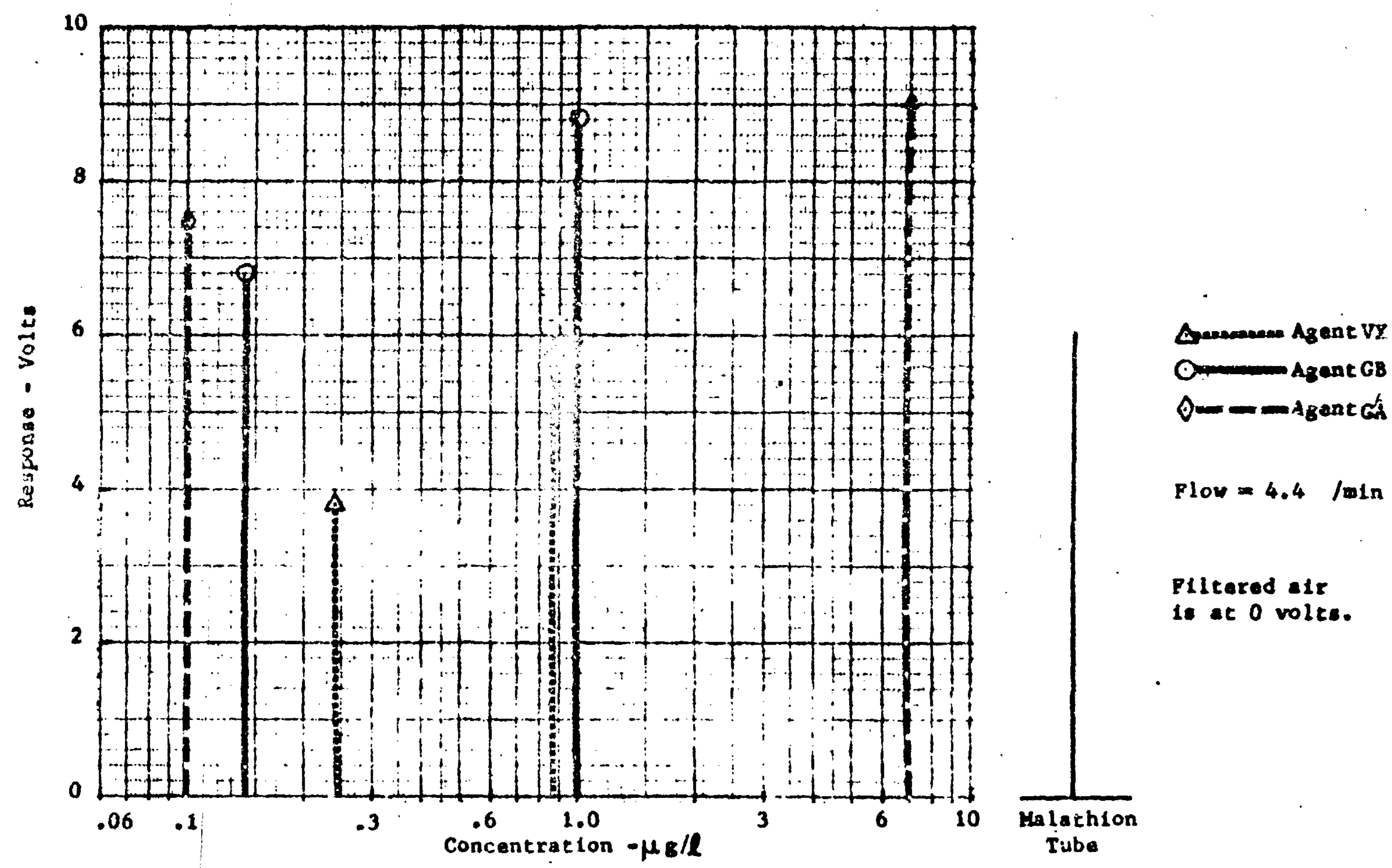



Figure 20. Agent Response of Experimental Cell E-2 with Grid at Plus Nine Volts

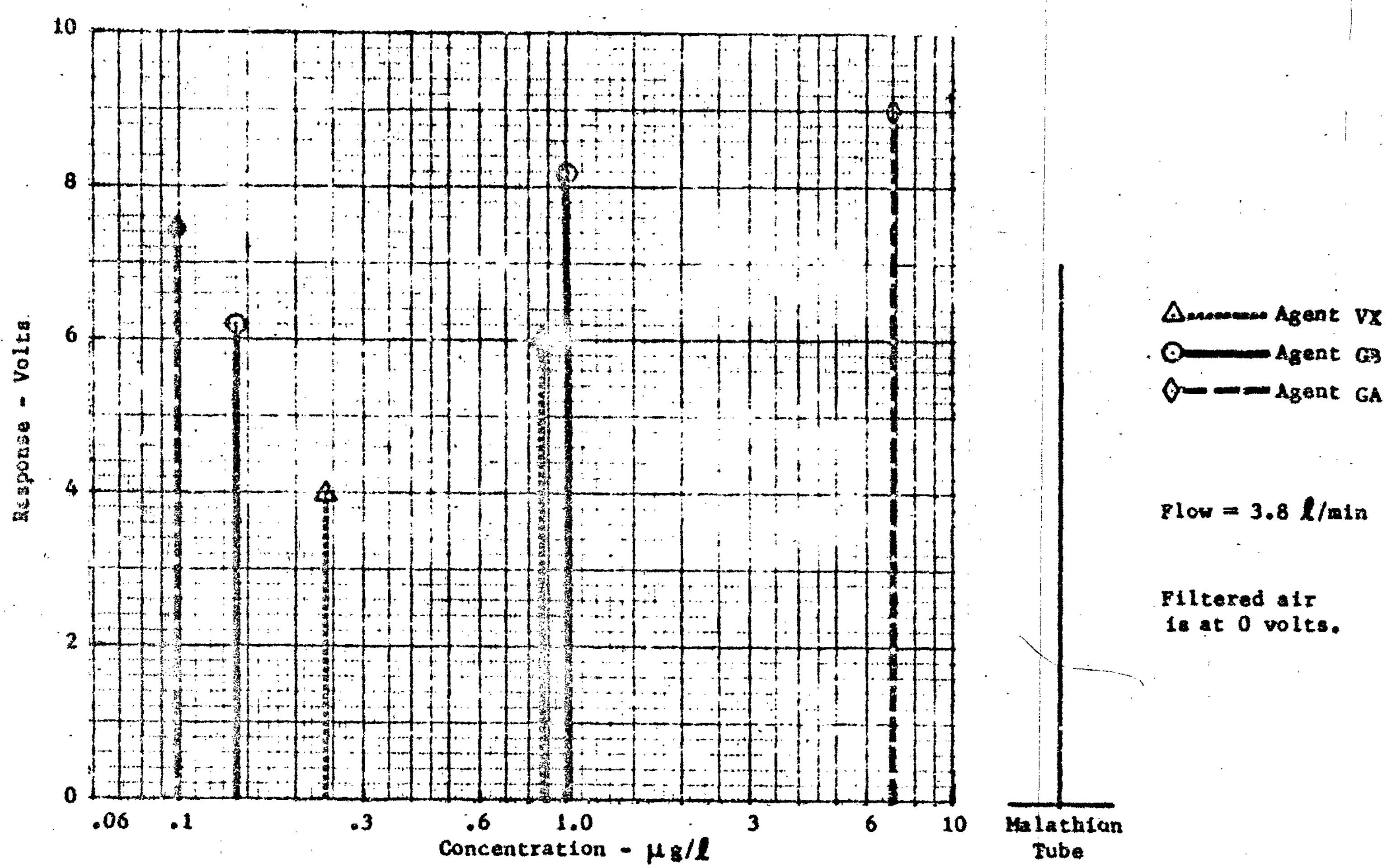



Figure 21. Agent Response of Standard IDS Cell

## E. Cell Material and Design

The baffle sections of the MADS cells are fabricated of 0.020 in.-thick Teflon material stacked on the stud to form the flow path of the cell. Support for the baffle is provided by gentle press fit onto the stud and by the small spacer washer around the outer circumference. The larger spacer washer is supported only around the circumference. With this type of design cold flow or creep of the Teflon material was a problem. To correct this deficiency, the use of aluminum sections coated with approximately 0.002 in.-thick Teflon material or with 0.002 in.-thick Parylene were evaluated. Parylene has many of the same properties as Teflon. Cells fabricated with the Parylene-treated components and Teflon components were tested with both simulants and agents. Figure 22 shows the cell design.

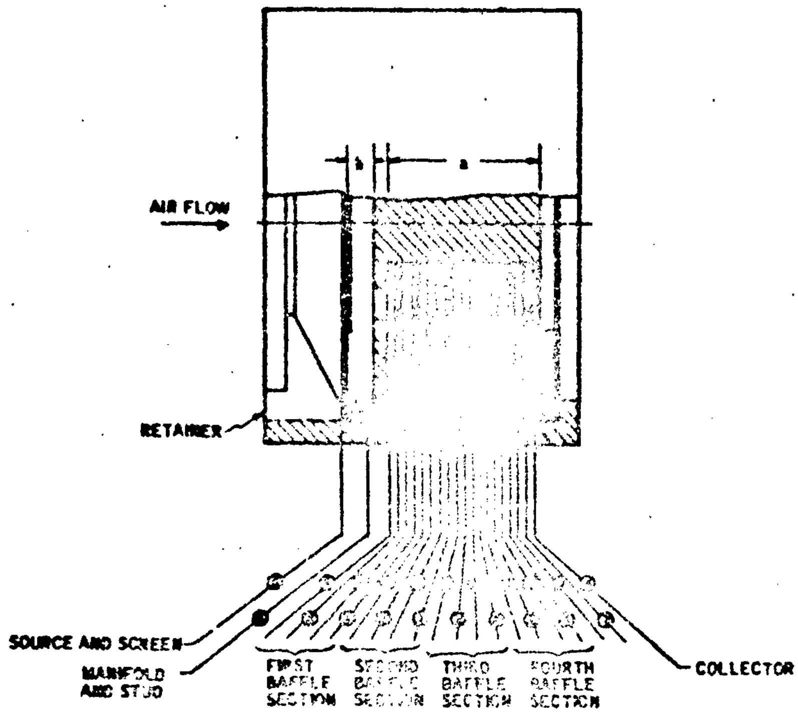



Figure 22. Cell Design

As noted the initial sections were fabricated with aluminum and coated with either the Teflon or Parylene. It was found that during the Teflon curing process, the heat warped some of the aluminum sections. The base material was then changed to a cold-rolled steel which corrected this problem.

Agent tests were conducted with both the Teflon and Parylene-coated sections. No noticeable difference could be observed between the two types of material with respect to response. Also no difference could be noted with the original solid Teflon type fabrication.

Since Teflon was used in the original design, the design was changed to Teflon-coated cold-rolled steel for the baffle sections. By staying with Teflon another possible variable was eliminated because Teflon has good chemical resistance, and good electrical insulation. It was also noted that the Parylene did not adhere to the surface as well as Teflon. The use of a primer may have helped. Teflon-coated components are used in the IDS modules.

### F. Cell Impedance

To compare the effect of flow impedance on the cell performance, two sensors with Teflon-coated baffle sections were built. One had the nominal 0.040 in. holes in the baffle sections and 7/32 in. hole in the spacer. The second cell had both dimensions reduced by approximately 0.004 in. The responses of these two cells were compared. Tests were also conducted with only the 7/32 in. hole diameter reduced. The responses obtained with both changes incorporated were compared to the original cell response with neither hole size decreased. The results are displayed in figure 23. Reducing the hole size in the baffles to approximately 0.036 in. increases the response 6 to 7% at similar flow rates. The 7/32 in. hole in the large spacer washer has little effect on the response. These experiments were originally conducted with an internal pump. It appeared that reducing the hole size decreased the response; however, the flow was also decreased. With an external pump a constant flow could be maintained. Since the decreased hole size decreases the flow, the effect of the increased cell response is lost at the lower flow. The 0.040 in. hole size appears to be a critical dimension and with the present pump size this diameter would appear to be a fundamental size for this design. This could, however, be a method of reducing the power requirements in the future.

### G. "O" Rings

The MADS units utilized Buna-N "O" rings as seals throughout the pneumatic path. The Buna-N "O" rings deteriorated with use and small cracks were visible. The "O" rings used on the ends of the sensor block were particularly susceptible. Small leaks in the pneumatic system would effectively reduce the flow at the intake and reduce the sensitivity of the detector. "O" ring representatives recommended the use of Viton "O" rings to minimize the deterioration of the seals in this application. This type of "O" ring is now being used in all of the sensors being life-tested and was incorporated into the three modified IDS modules. No evidence of deterioration has been noted with the use of Viton material. It has however been noted that the Viton is less resilient then the Buna-N and wetting the "O" rings with water during assembly is recommended.

### H. Cell Life Tests

Several modified cells were fabricated during the early part of August for life testing. The purpose of these tests was to evaluate several design changes aimed at improving the long-term sensitivity of the cells. These modifications included larger sources, coated metal baffle sections and improved contact material.

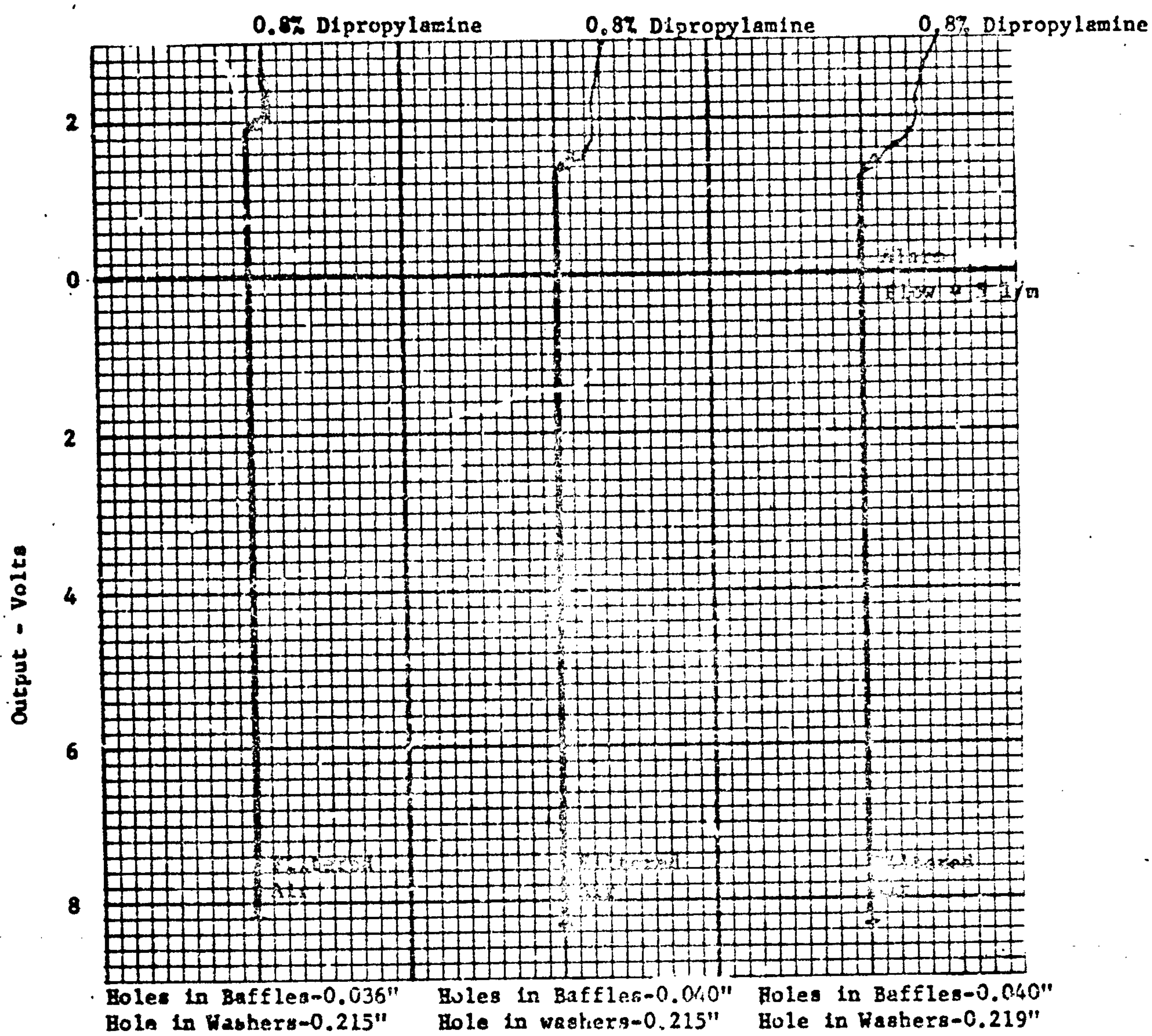



Figure 23. Cell Response vs a Function of Flow Impedance

The response magnitude of the cells to known concentrations of agent was recorded at the start of the life tests. Also the units were periodically exposed to a simulant. After approximately three months of continual operation, the sensors were again exposed to agent for comparison to the original data.

Results of the qualitative tests with malathion are illustrated in figure 24. The magnitude of the malathion responses shown has been fairly constant over the test period. These particular tests were conducted with standard IDS sensor modules which have shown some decrease in flow rate during the tests. No correction has been made in the data for this decrease in flow and no attempt has been made to balance the flow compensation of these units. As noted on figure 24 unit #19, the baseline or filtered air had been more irregular than the baselines of units #11 and 16, which results in an irregular response curve for unit #19. The cause of this irregular baseline was not isolated, but could be due to the electronics of this particular unit or a poor connection.

During the week of November 13, 1972 the cells were again exposed to agent. The original agent responses resulting from tests in August are compared in figures 25-30 with the agent responses obtained three months later. This comparison of the two agent test series shows some variations in the agent responses. However, these are probably within the expected accuracies for repeating the agent concentrations and of the instrumentation with the exception of unit #11. This unit indicates some loss in sensitivity. The cells in this device are fabricated with standard Teflon baffles. This may be an indication that the internal flow path has changed slightly which favors the use of the Teflon-coated baffles.

### I. Humidity Tests

The effect of varying the background humidity on the IDS responses had not been tested previously with nerve agents with the exception of a few tests conducted during the previous program. These were conducted in the 20 to 60% relative humidity range with agents 'VX' and 'GB'. These experiments showed little or no change in cell response within this humidity range. During the agent tests conducted in November, several cells were tested with agent 'GB' and the background humidity varied from the 20-30% range to the 80-90% range. A comparison of these responses is shown in figures 31-33. These tests, conducted with only low concentrations of agent 'GB', showed an approximate decrease in response of 15% at the high relative humidity as compared to the response at 20-30% relative humidity.

## II. SENSOR MODULE CALIBRATION CHECK

Functional operation of the IDS detector can be checked by exposing the inlet of the unit to a simulant and either monitoring or observing the detector output. Malathion is one of the simulants which is used and appears to have response characteristics similar to several of the c.w. agents. DDVP and Disyston are two other simulants which work well. Calibration is accomplished by monitoring the response to a controlled concentration of a simulant or agent and adjusting the alarm level accordingly.

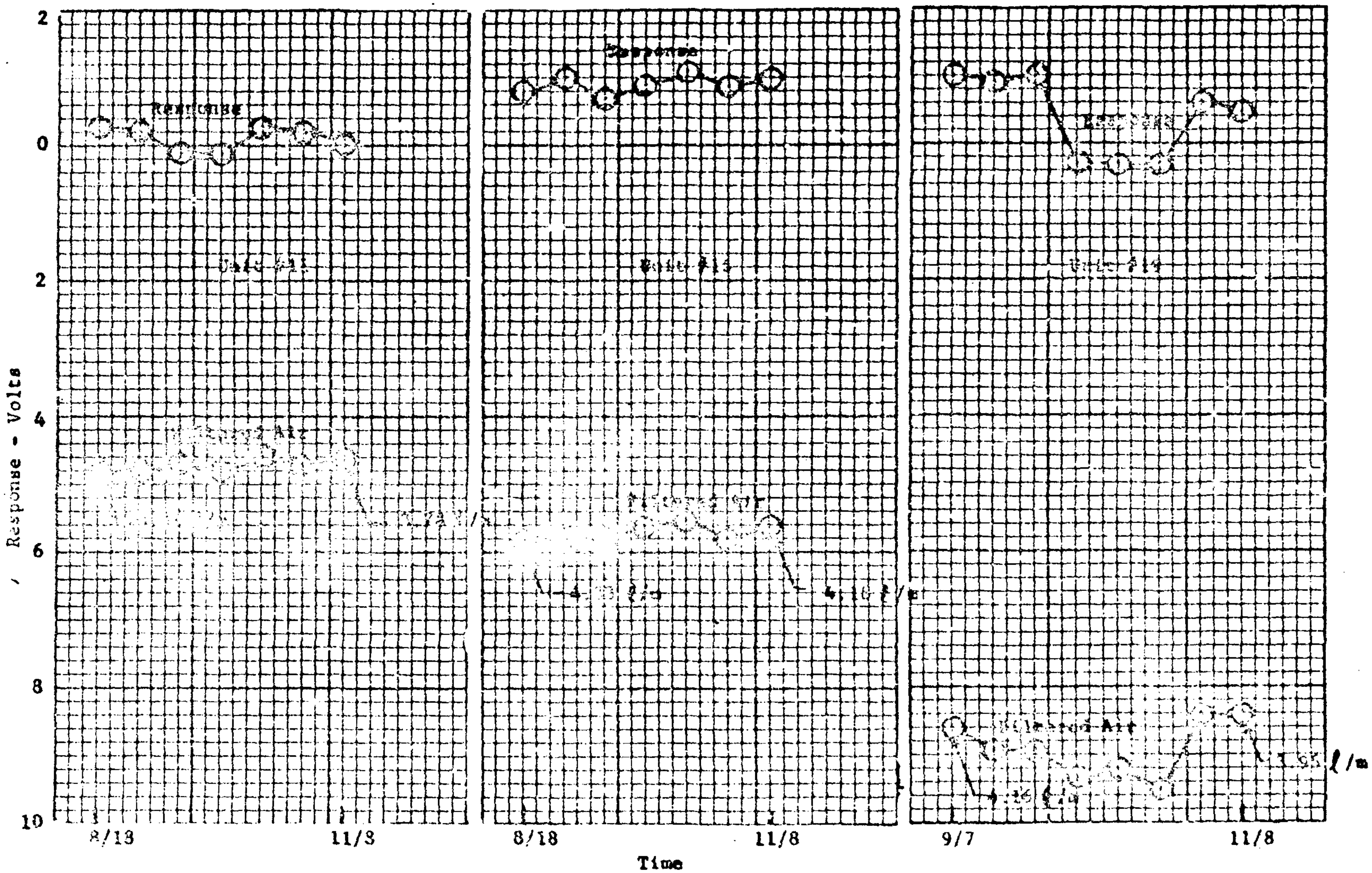



Figure 24. IDS Response To Malathion With Time

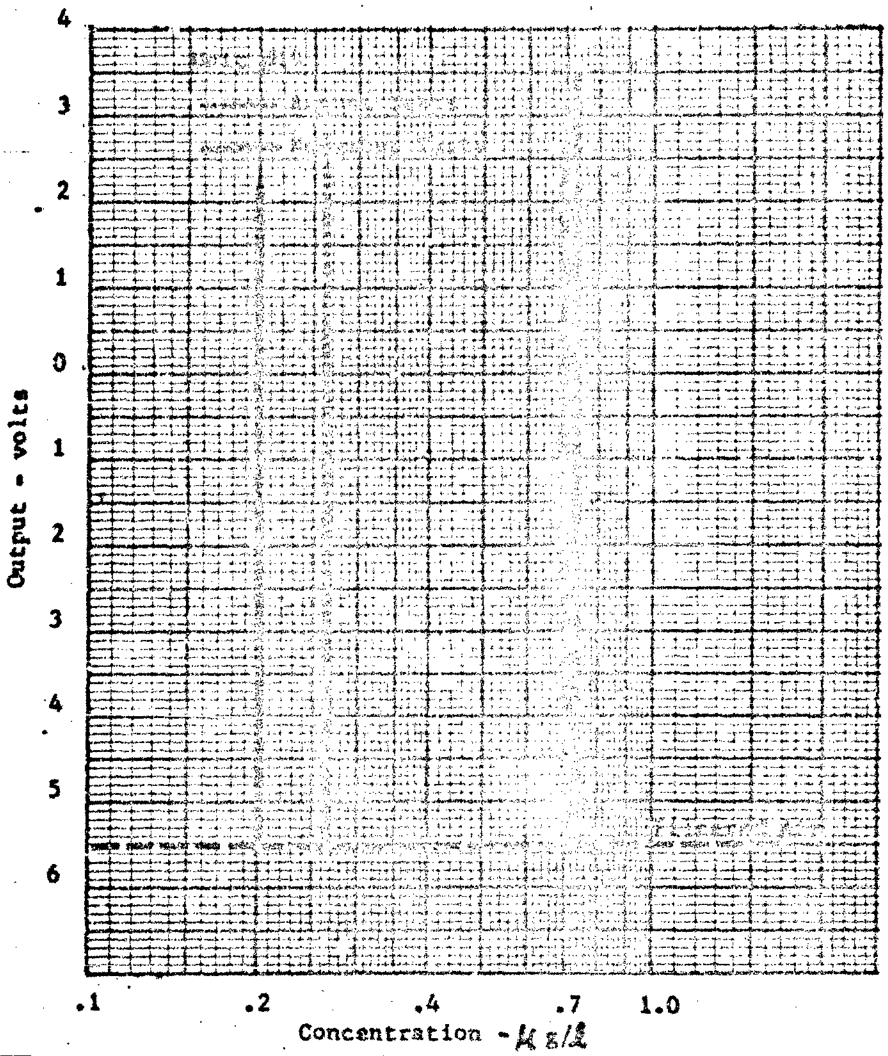



Figure 25. Concentration Agent 'GB' Versus Response

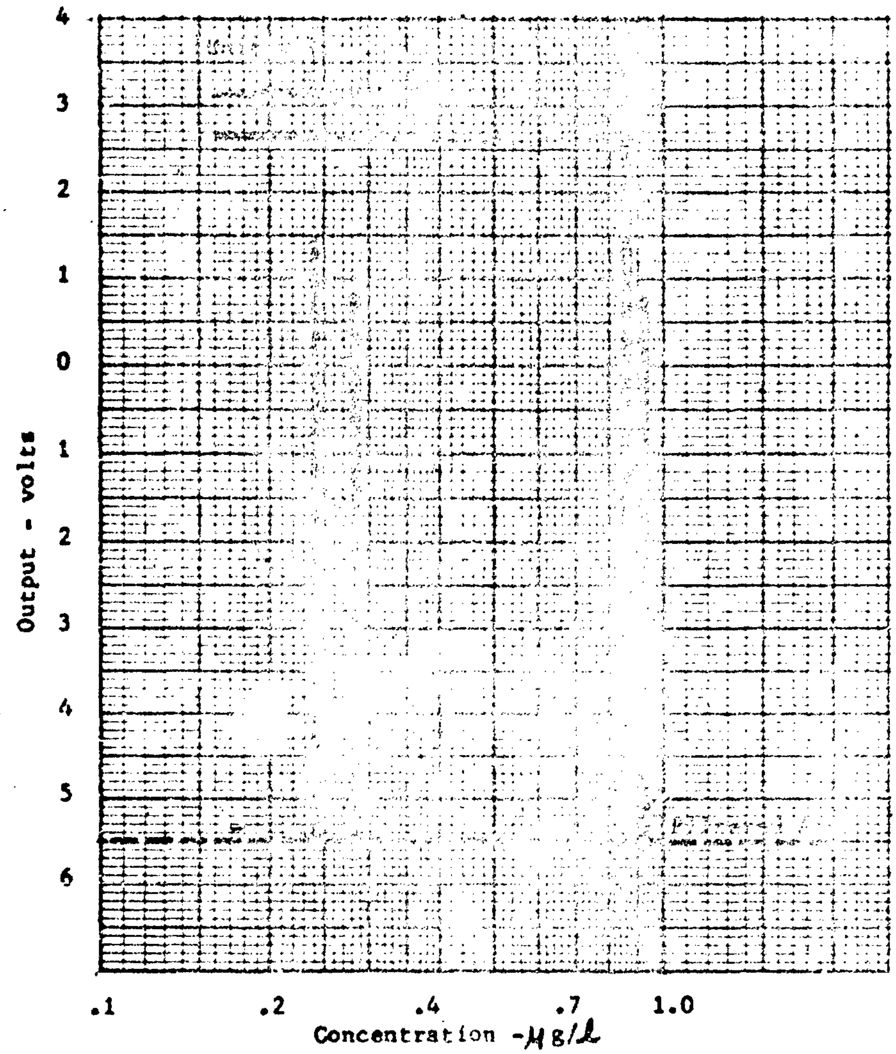



Figure 26. Concentration Agent 'VX' Versus Response

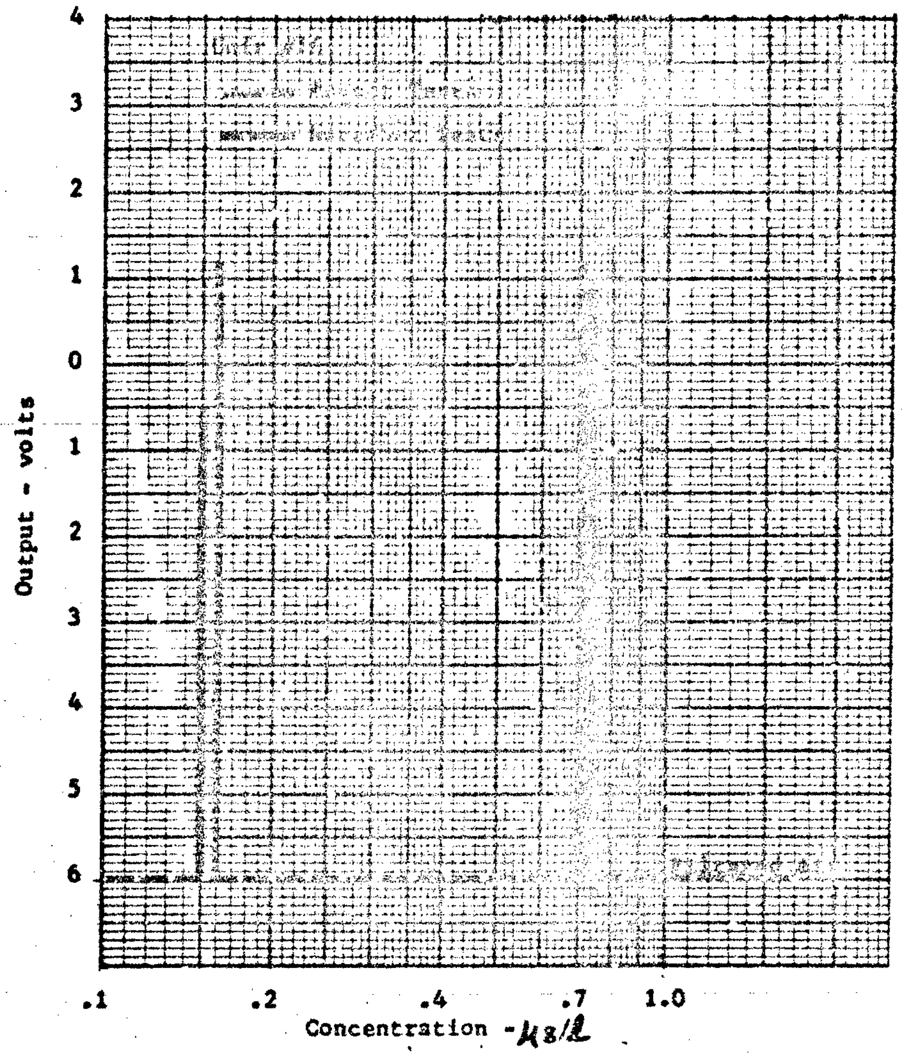



Figure 27. Concentration Agent 'GB' Versus Response

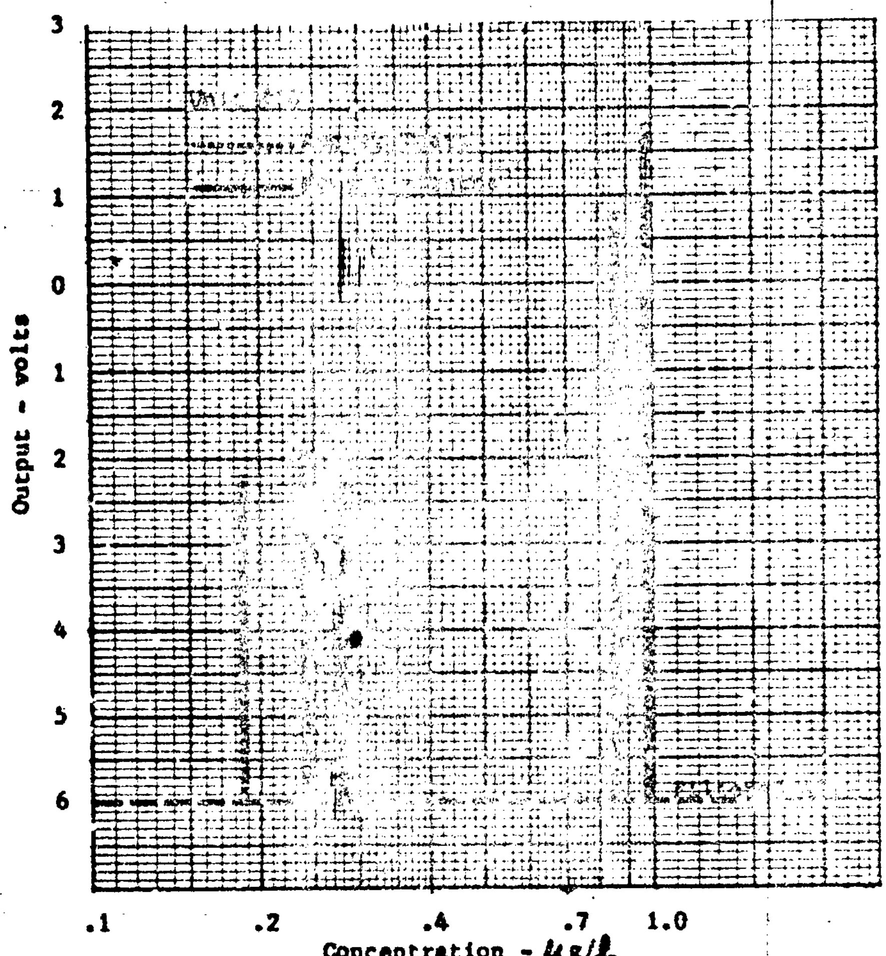



Figure 28. Concentration Agent 'VX' Versus Response

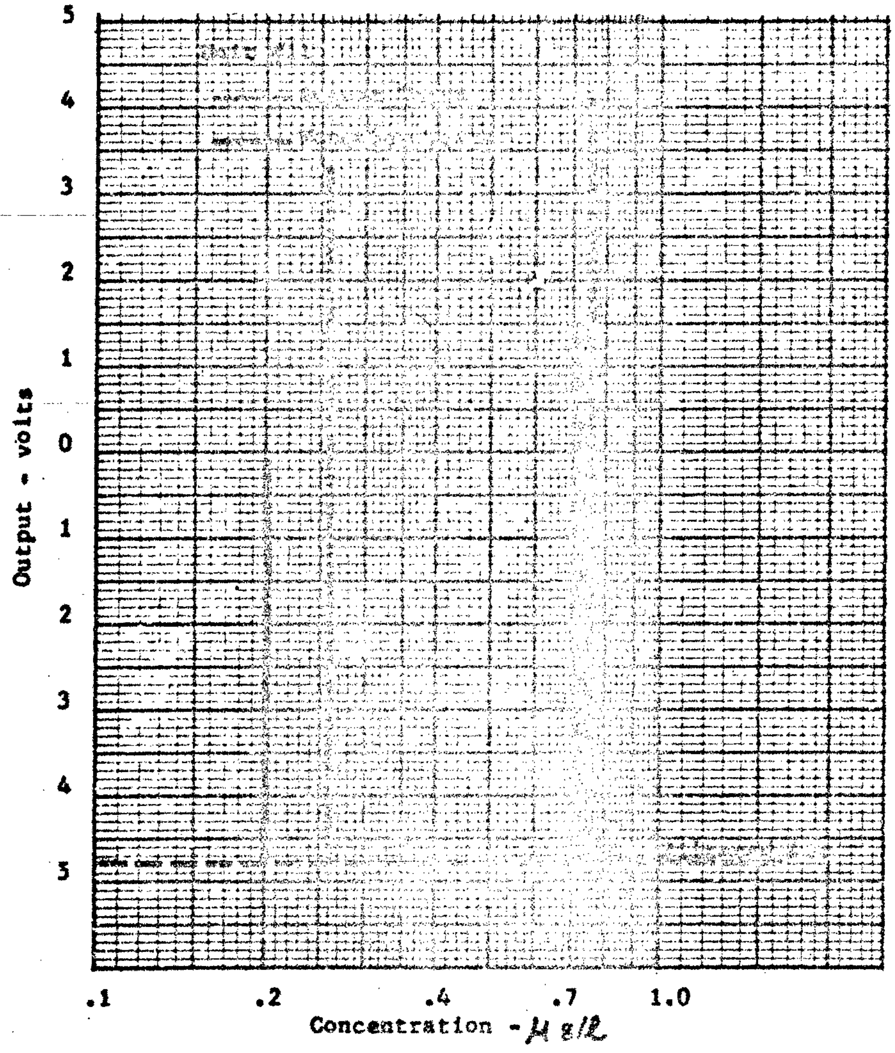



Figure 29. Concentration Agent 'GB' Versus Response

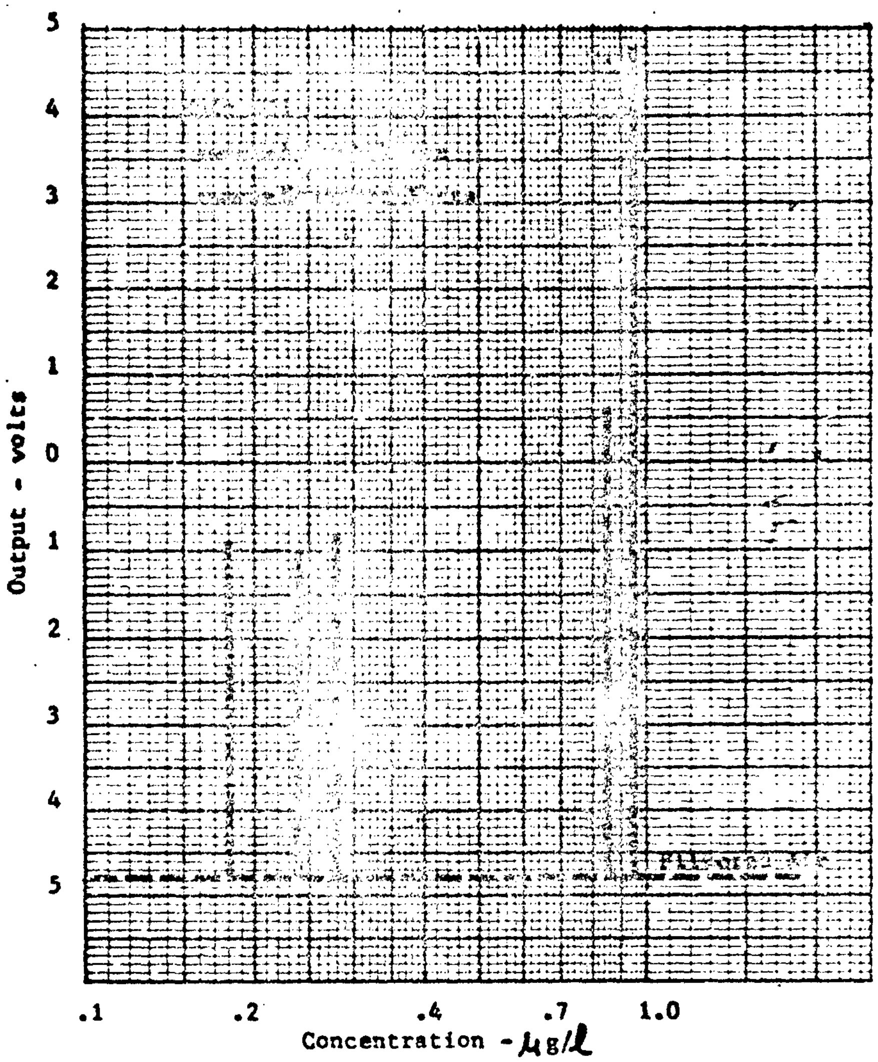



Figure 30. Concentration Agent 'VX' Versus Response

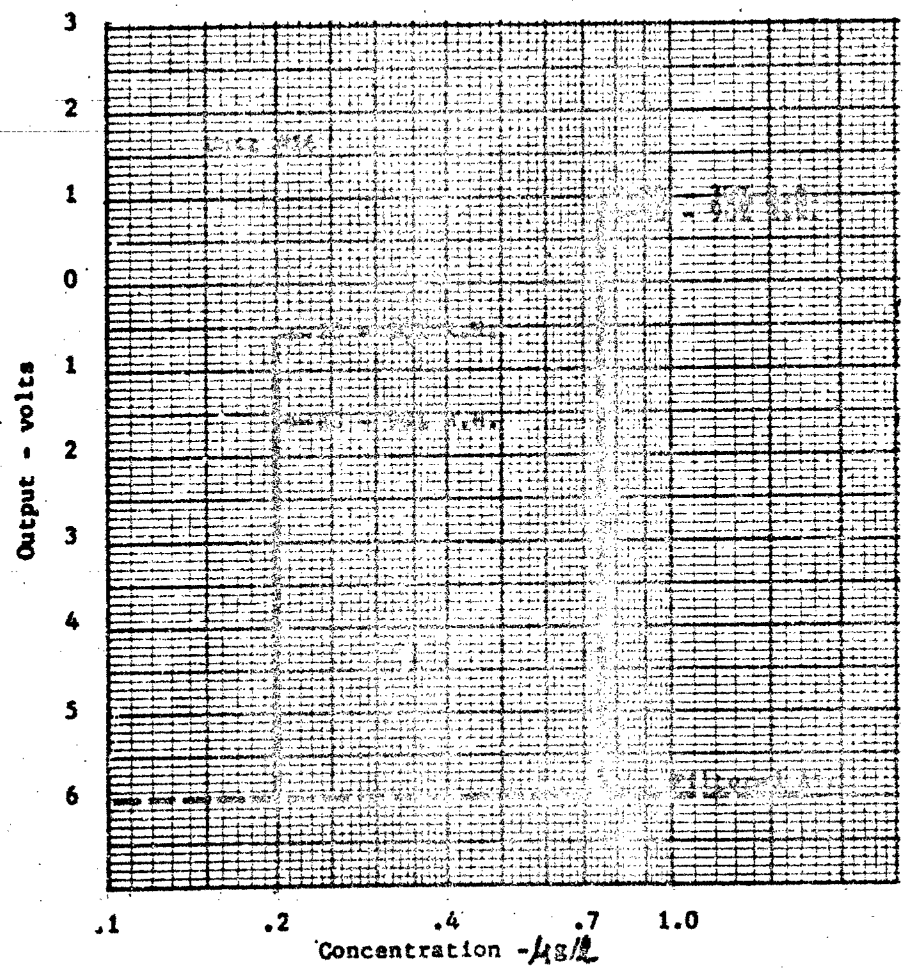



Figure 31. Response To Agent 'GB With Varying Humidity

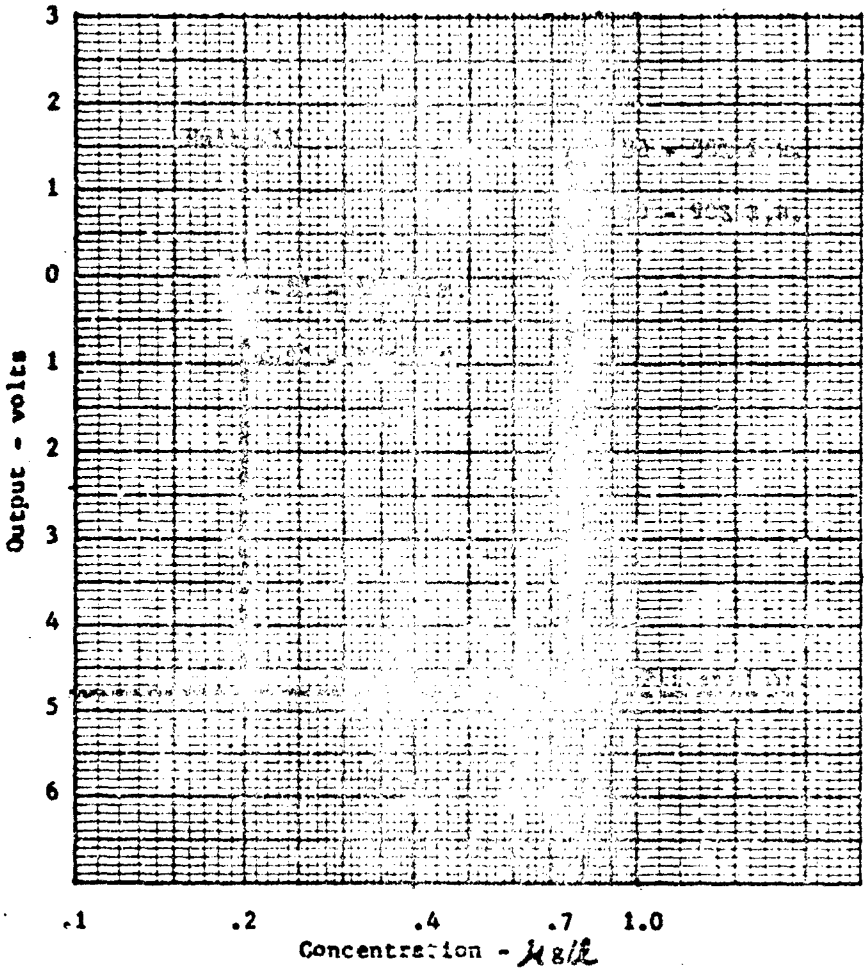



Figure 32. Response To Agent 'GB' With Varying Humidity

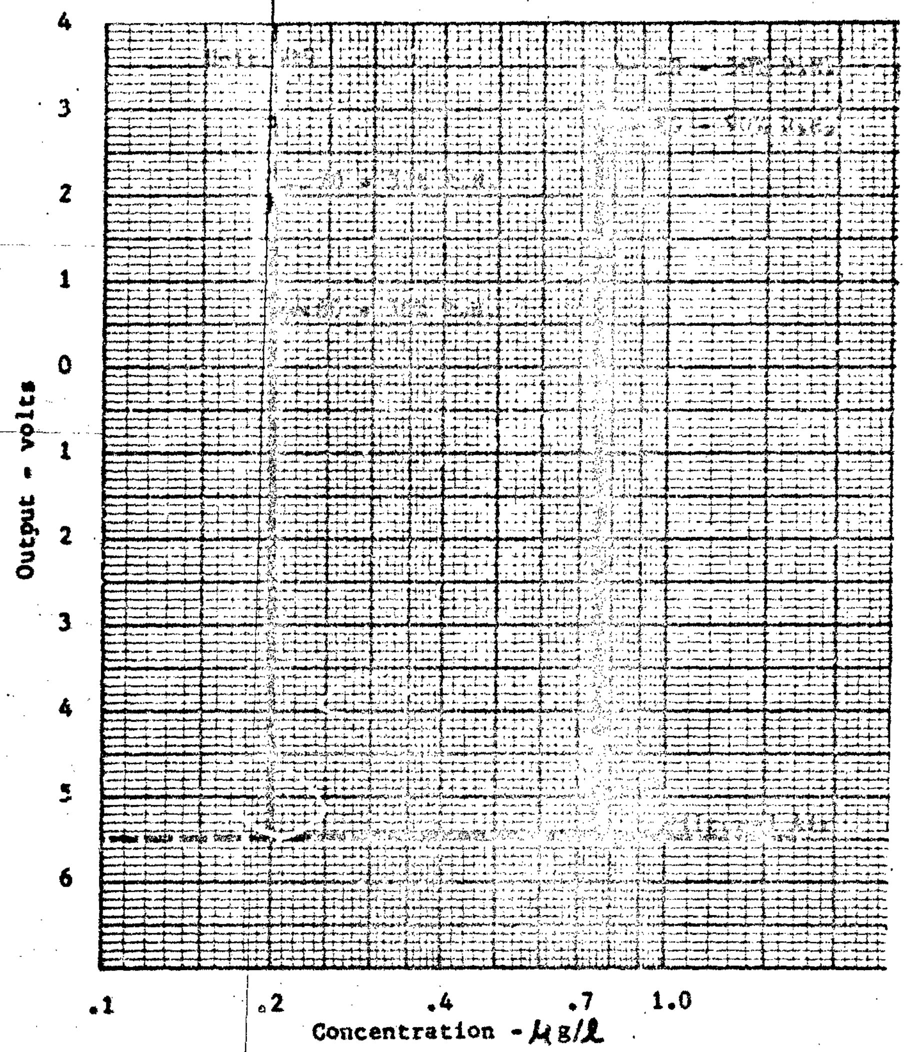



Figure 33. Response To Agent 'GB' With Varying Humidity

Two alternate methods of providing a sensor calibration check for use in the field or maintenance shop were studied. One method which was considered and adopted is the use of a separate portable calibration fixture. The fixture is mated to the intake of any of the IDS sensor modules for functional and calibration tests. With this type of approach only one calibration fixture is needed to test any number of detectors. A temperature control feature is incorporated. The air temperature entering the calibration fixture affects the simulant concentration which enters the detector. Heating the fixture is required for this approach.

A second method considered was to provide an internal calibration feature. With this approach, the intake sample could be diverted by valving through the calibration section containing a simulant. The intake air could be heated during the calibration check similar to heating of the intake air during normal operation. In addition the calibration fixture would always be at a constant temperature. Advantages and disadvantages of both methods are outlined below:

External Unit - Advantages

- Minimum hardware cost for sensor module
- Concept more nearly approaches that of a single reference than would a calibration device internal to each sensor module
- Cross-check capability from sensor module to sensor module supports faith in calibration device
- Sensor module complexity unchanged
- Simulant leakage could be detected by comparison with air signal
- Antitampering not required
- Lower cost of simulant replacement, if found necessary

External Unit - Disadvantages

- Less convenient than internal unit
- Less accessible than internal unit
- Requires separate power source

Internal Unit - Advantages

- Convenient
- Accessible
- Small additional weight to sensor module
- No additional power requirement

Internal Unit - Disadvantages

- More expensive hardware approach
- Simulant in each SM departs from concept of a universal reference
- Failure of self-test simulant might go undetected
- Sensor module becomes more complex
- Possibility of simulant leakage
- Self-test needs antitamper to avoid false alarms
- Higher cost of simulant replacement, if found necessary

Both methods were considered and with concurrence of the project officer a separate calibration fixture was considered the better approach.

A photo of the calibration module is displayed in figure 34. The unit's dimensions are approximately 7 1/2 x 7 1/2 x 8 1/2 inches.

Initially a prototype of the calibration fixture was fabricated and the design tested. The prototype unit utilized only one channel or simulant. Operation of the A and B channel was tested by altering the flow path to supply either saturated or diluted simulant vapors to the sensor. Saturated vapors were required for checking the B channel while a much smaller concentration of simulant was needed to test the A channel. This type of design was tested with the prototype using both malathion and DDVP as possible simulants. However with either of these simulants this design did not work well. Malathion worked well for the A channel but too large of a concentration was required to test the B channel. DDVP worked well for the B channel however too small of a concentration was required for the A channel test. In addition, only one inlet was used for the prototype. The time required for the inlet to purge after subjecting the sensor to a simulant was found to be excessive. The calibration module therefore now has two inlets, one for filtered air and one for the simulants.

A block diagram of the field calibration module is shown in figure 35.

The following steps should be followed when using the field calibration module to test the IDS units.

1. The field calibration unit should be plugged into 115 v ac and the power switch placed in the on position. The unit should be allowed a minimum of 15 minutes warm-up. The sensor module to be calibrated should also be allowed to stabilize.
2. Valve number 1 should be placed in the filtered air position. Place the field calibration module on the sensor module with the rear most outlet of calibration unit over the intake of the sensor module.
3. The signal cord of the sensor module should be mated with the input jacks on the front of the calibration unit. The jacks and inputs are color coded.
4. Allow a few minutes for the sensor module to stabilize on filtered air. Record the flow rate of the unit. The flow should be 4.25 ± .15 nl/min. The flow rate is adjusted by the center trimpot on the side of the sensor module. Clockwise rotation increases the flow.
5. Record the voltage output of both the A and B channels which is displayed by the meter on the front surface of the calibration module. The two position switch over the meter indicates which channel is displayed by the meter.
6. Remove the calibration module from the IDS sensor. Change the position of valve #1 to simulants. Valves A and B should be in the by-pass position. Place the calibration module on the sensor unit with the front most outlet of the calibration module mated with the sensor intake.

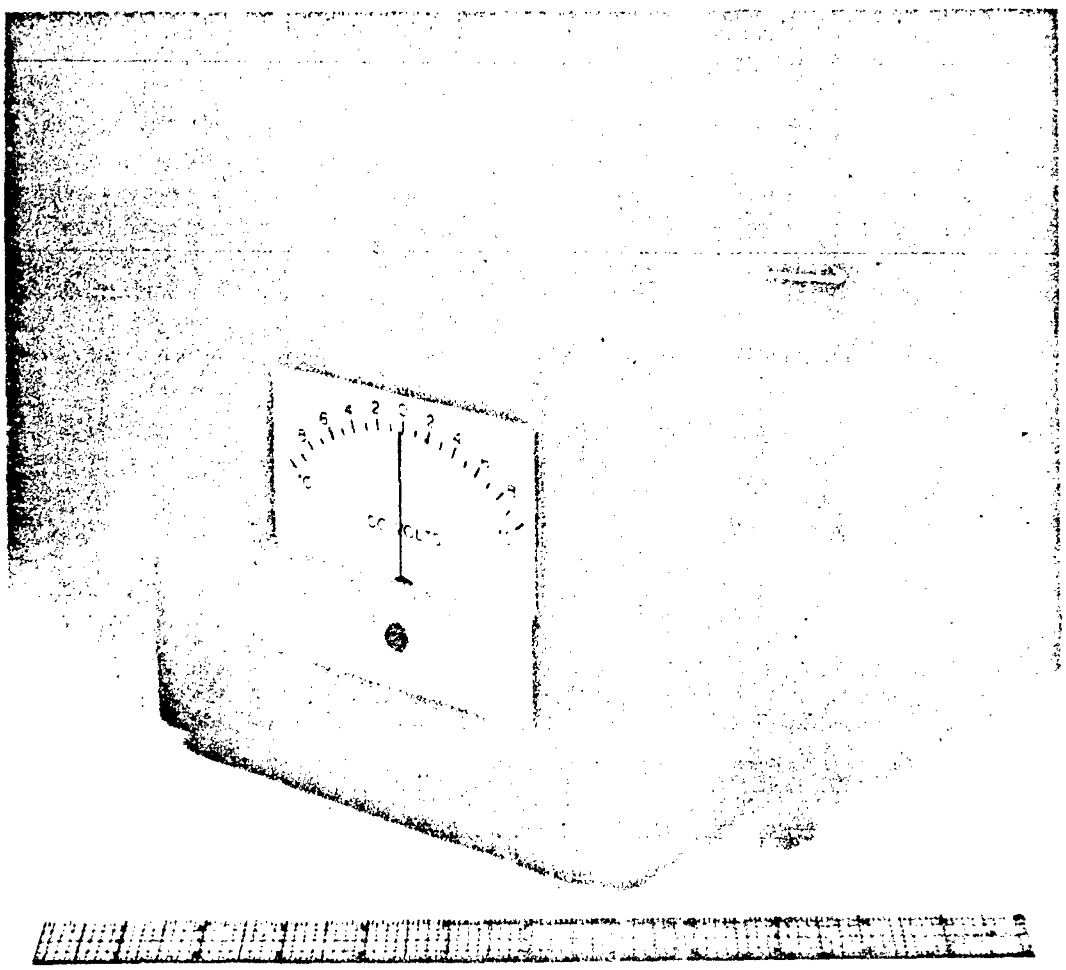


Figure 34. Field Calibration Module

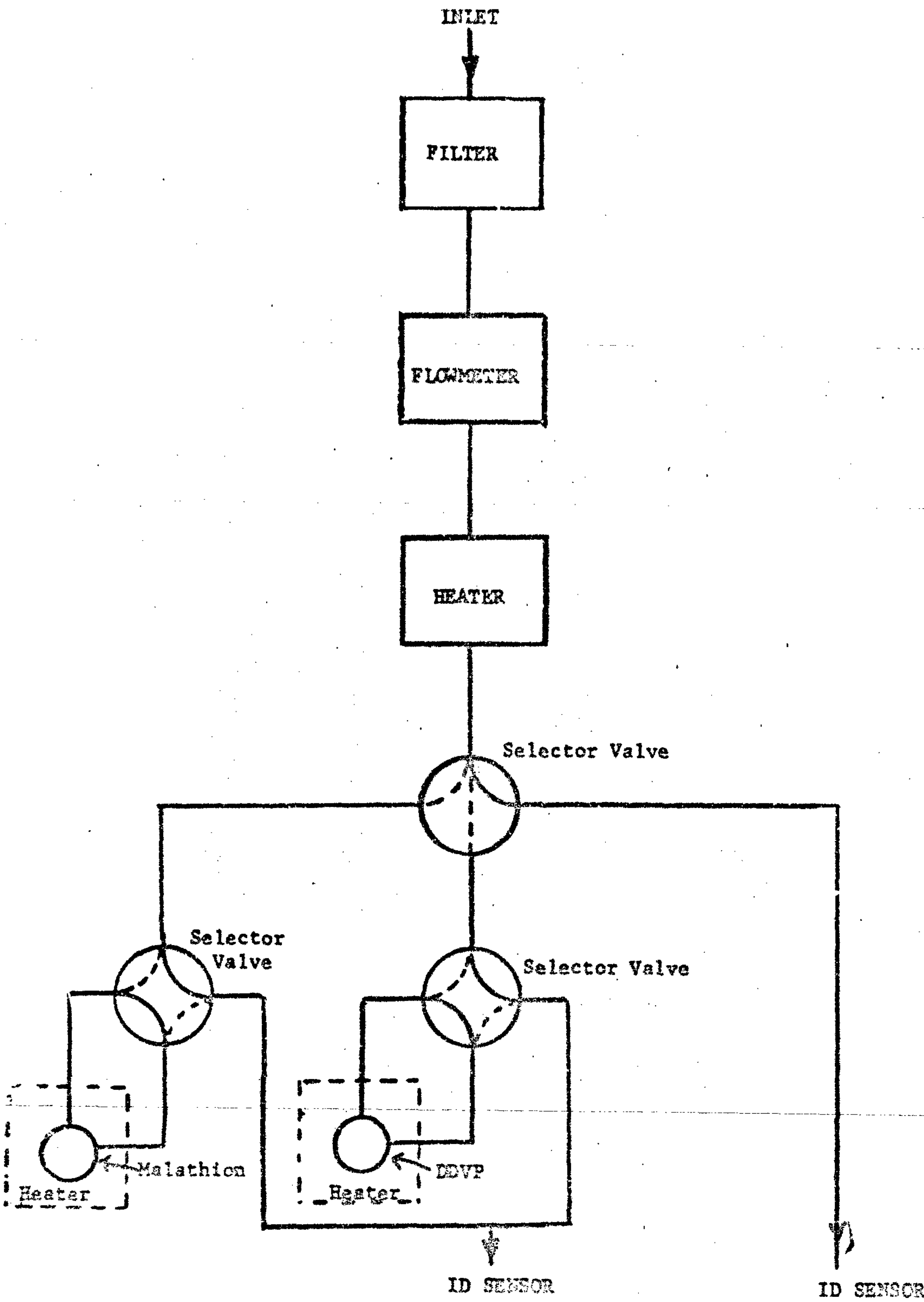



Figure 35. Block Diagram of the Field Calibration Module

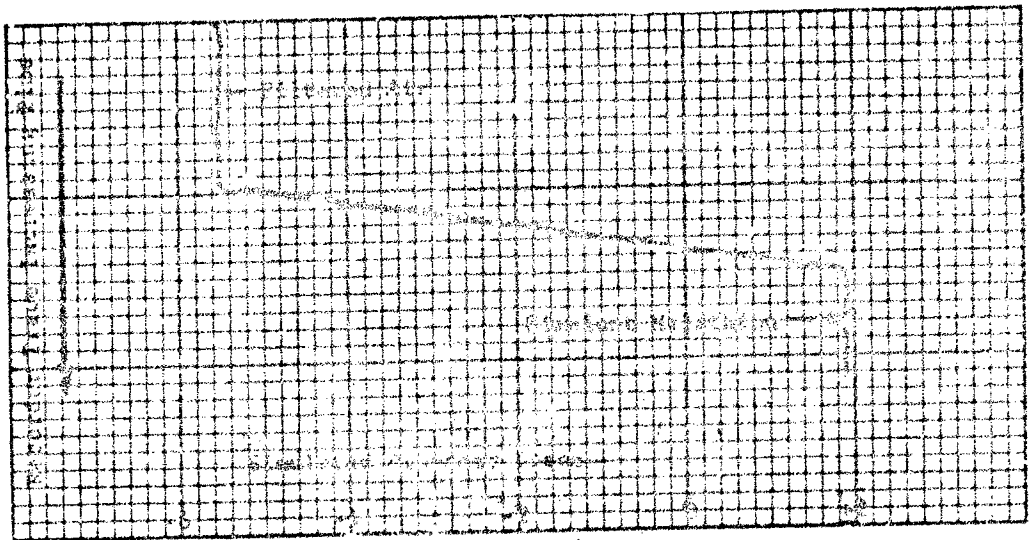
7. Turn valve A to the simulant position. The meter switch should be in the A position. Allow the response to stabilize (approximately 30 seconds) and record the channel A output. This response should be + 2 ± 0.5 volts. Proper adjustment of the channel is as illustrated in figure 36. The alarm level is adjusted by a labeled trim pot on the side of the sensor module. Clockwise rotation of the pot increases the percentage of the total response above the alarm level.
8. Turn valve A to the bypass position and allow a few minutes for the simulant to purge.
9. Turn valve B to the simulant position and change the meter switch to the B position. Allow the response to stabilize. Record the voltage reading. This response should be + 3 ± 1 volts. Proper adjustment of channel B is as illustrated in figure 37. Adjustment of the B channel is similar to the A channel adjustment. Clockwise rotation increases the percentage of the total response above the alarm level.
10. Return valve B to the bypass position and allow several minutes for the simulant to purge.

## III. EXTERNAL FLOW COMPENSATION, FLOW RATE, AND ALARM LEVEL ADJUSTMENTS

Adjustments of the alarm level settings were accomplished in the MADS by removing the top cover of the detector and adjusting a trimmer potentiometer. This adjustment varied the percent or amount of flow cell output which was differentially added to the $S^o$ cell and offset the baseline below the alarm level accordingly. However, since some variation in sensitivity of different $S^o$ cells had been noted, the gain of the $S^o$ preamplifier had to be adjusted to match the flow compensation cell. The preamp gain was altered by changing a fixed resistor. In addition to the inconvenience of removing the cover to make the alarm level adjustment, electrical noise was a problem with the cover off making the adjustment fairly difficult.

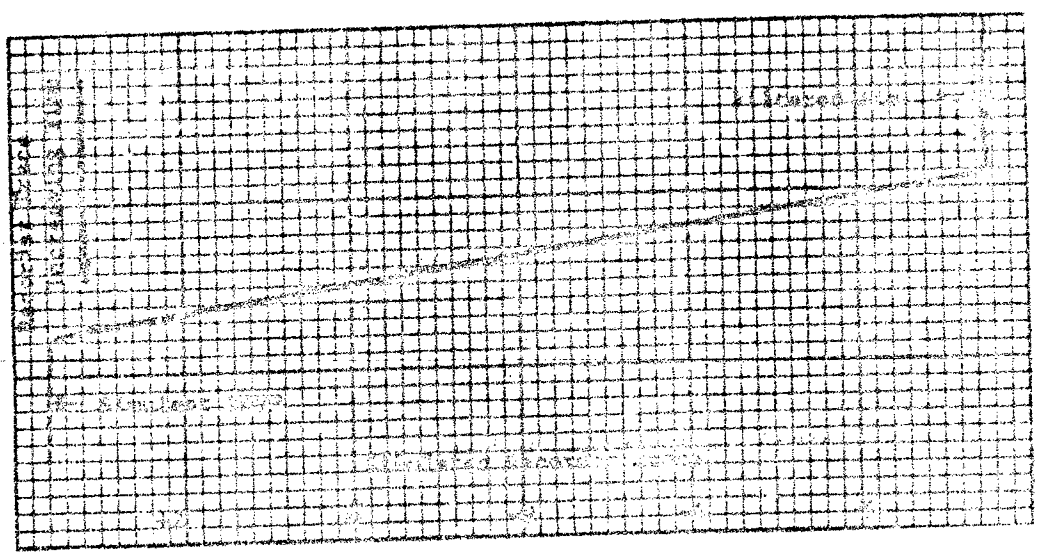
Adjustments for both an alarm level/balance setting and for the degree of flow compensation were incorporated into the modified IDS detectors. These adjustments are externally accessible and accomplished with adjustable potentiometers. The degree of flow compensation is controlled by varying the gain of the flow cell preamp. With the flow compensation properly adjusted, the alarm level setting is adjusted by adding a d-c bias to the input of the differential amplifier. This bias is varied with an adjustable potentiometer without affecting the degree of flow compensation. To prevent tampering with the adjustment potentiometers, and for environmental protection, the adjustment potentiometers are enclosed behind an access disk.

The access disk is on the right side of the sensor module when facing the unit. Five trim pots are mounted in back of a circular disk which can be rotated for access to the pots. A small screw driver is used to adjust the pots. A seal is provided between the case and the disk. The function of the five pots is to adjust the alarm level of both channels (two pots), adjust the amount of flow compensation of both channels (two pots), and adjust the flow



Sensor Output-Volts

Figure 36. Calibration of A Channel



Sensor Output-Volts

Figure 37. Calibration of B Channel

rate (one pot) by varying the speed of the motor. The flow rate adjustment is outlined in greater detail in section VII. Each of the preceeding functions is identified by lettering on the side of the module. To seal the unit and prevent rotation of the access ports, a screw located in the center of the disk is tightened in the closed position.

Clockwise rotation of the trim pots has the following functions:

- Alarm level increased
- Amount of flow compensation increased
- Flow rate increased

## IV. PROPORTIONING STUDIES

A characteristic decrease in sensor response to high concentrations of CW agent GA exists. A peak response is obtained at low concentrations with significant dropoff of the signal level occurring at higher concentrations. A modification, which reduces the CW agent concentration prior to entering a second cell by filtering out most of the agent (approximately 90%, was demonstrated to be effective for sensitivity to high concentrations. The modification affects only channel B, with alarms due to high concentrations of GA being noted on this channel. The filter configuration is shown in figure 38.

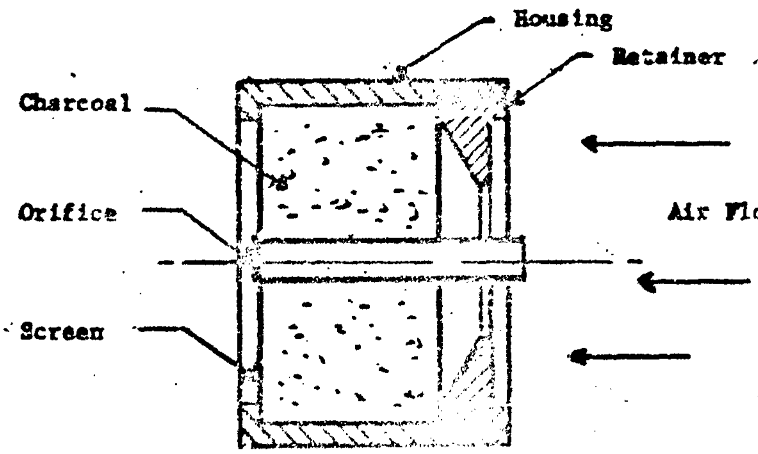



Figure 38. Dilution Configuration

As noted from figure 38 air stream enters the first cell, which is used to sense the presence of agents and is displayed by channel A. The air stream then flows into the filter configuration. A large percentage of the agent in the air stream is absorbed by the charcoal as it passes through the filter device. A small percentage of the air stream and agent however will pass through the orifice and be mixed with the filtered air which has passed through the charcoal. This mixture then enters the second cell, which is identical to the first cell. Since the second cell is exposed to a lower concentration of agent, this cell will indicate the presence of high concentrations of agent GA without saturating.

The B channel is also flow compensated whereby the output of the second cell is combined with the output of the flow cell as shown in figure 39.

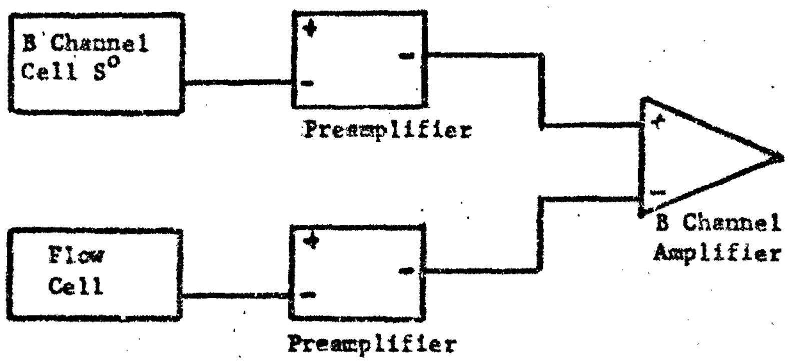



Figure 39. Block Diagram of B Channel Flow Compensation

Tests were conducted with several different sizes of orifices in the filter device. A 0.015" diameter orifice appears to give the desired dilution ratio. This is estimated to be approximately 25 to 1.

Originally large variations were noted between different devices with respect to the ratio obtained. The devices all had similar orifices with other features also similar. It was found that the method of filling or packing the charcoal within the device was critical. Apparently the density of the charcoal granules and preferred flow paths with the charcoal were affecting the efficiency of the device. A vibrator was then used consistently to pack the charcoal. This eliminated most of the differences among units.

This feature was incorporated into the three modified IDS units. An illustration of how the configuration works with agent is shown in figure 40. Note that at higher concentrations as channel A saturates and drops off in signal, channel B has alarmed and extends the effective range of the IDS system.

## V. AIR SAMPLING INLET SYSTEM

The air sampling inlet system used on the MADS sensor module generally works quite well. However, when the sampled atmosphere contains an extraordinary concentration of dust and salt spray, these contaminants pass into the system. A major portion of these contaminants seems to deposit within the heater block in the vicinity of the 12 holes constituting the effective inlet to the heater.

Design and fabrication of a modified inlet subsystem was completed, Figure 39a. The main difference in the new design is the addition of a dust settling chamber which can be easily cleaned and which provides a region for future improvement of dust collection such as by the inclusion of baffles. The new inlet uses the same heater button and heat exchanger as the previous design. The inlet path length is now slightly longer, but the difference in agent response time is minor.

The new inlet system was installed in an IDS sensor module which had the most recent cell configuration. For comparison this IDS sensor module and an IDS unit which had an old style inlet were dust tested in parallel. Both sensor modules were tested with simulants prior to the dust tests.

### A. Dust Tests

To perform these dust tests both instruments were located in an open-loop wind tunnel in the positive pressure (atmospheric) section. During the exposure, a dust laden air stream flowed by the instruments. Both instruments operated throughout the entire exposure and were located in the tunnel in such a way that the minimum clearance between themselves and the surface of the duct was a minimum of four (4) inches. The sensor modules were oriented vertical with the back of the instrument upstream and perpendicular to the general flow stream for maximum dust ingestion. During the exposure the following parameters were controlled: air temperature, humidity, velocity and dust concentration.

The exposure cycle consists of four steps:

<u>Step 1</u>

| | |
|---|---|
| Air temperature | 25 ± 1°C |
| Relative humidity | (30 ± 5) % |
| Air velocity | 5 ± 0.7 m/s |
| Dust concentration | 0.06 ± 0.04 $g/m^3$ |
| Exposure time | 6 hours |

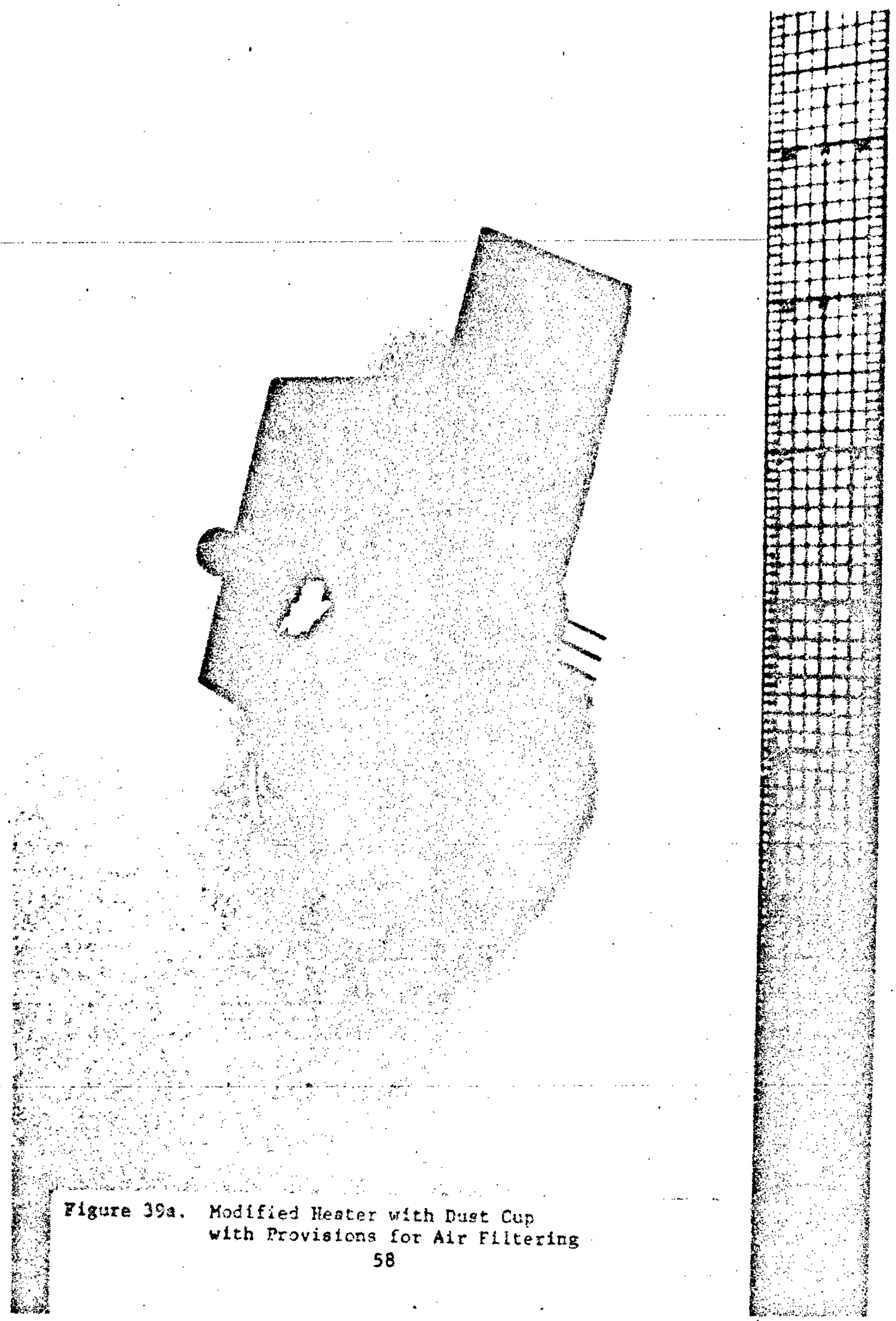


Figure 39a. Modified Heater with Dust Cup with Provisions for Air Filtering

Step 2

| | |
|---|---|
| Air temperature | $(60^{+0}_{-2})$ °C |
| Relative humidity | <35% |
| Air velocity | 0.86 ± 0.57 m/s |
| No dust feeds and an exposure time of | 16 hours |

Step 3

| | |
|---|---|
| Air temperature | $(60^{+0}_{-2})$ °C |
| Relative humidity | <35% |
| Air velocity | 5 ± 0.7 m/s |
| Dust concentration | 0.06 ± 0.04 $g/m^3$ |
| Exposure time | 6 hours |

Step 4

All controls including both IDS sensor modules were turned off and the instruments were allowed to return to standard ambient conditions. The IDS sensor modules were then wiped clean but not cleaned by air blast or vacuum.

## B. Inlet Modification Test Results

The two sensor modules were tested with simulants and otherwise examined before and after the dust tests. Following the first dust test, each unit was fitted with a screen filter on the inlet and the dust tests were repeated. Again the two sensor modules were tested with simulants and otherwise examined before and after the second dust test.

Briefly, the dust tests increased the concentration of malathion required to alarm by a factor between 2 and 3 and increased the response time a small amount. Readjustment of one sensor module of flow and alarms restored the performance probably within experimental error. It should be noted that the improved alarm and flow compensation circuits included in the three units delivered to Edgewood Arsenal in mid-May were not available for units employed in the dust tests.

Whether the sensor modules passed the dust tests would appear to be a matter of judgement on the part of participating personnel. However, normally the units would be subjected to a much lower accumulation of dust prior to field inspection and adjustment if necessary; with such reasoning the units weathered the test quite well. Furthermore, the sensor modules were oriented for maximum dust ingestion and were set for a flow ~10% higher than that of the three operational units delivered in mid-May. The tests were run with what is regarded by Edgewood Arsenal personnel to be a dust concentration in an extreme condition (0.06 $g/m^3$) instead of the moderate condition (0.01 $g/m^3$). In the MADS program the units nearly passed the dust test with a dust concentration of 10.6 $g/m^3$, a concentration existing in the dust clouds at tracks of tanks, a factor of 177. greater than the extreme condition above.

The use of a screen filter (figures 40, 40a, 40b) on the inlet was suggested by a laboratory test in which the pressure drop across a sensor module increased rapidly with time. Examination of the source screen of the first cell revealed a nearly clogging mat of lint and large particles. The screen filter was intended to remove such large particles with the thought that they exist indoors and that they and others including grass, insects, etc., exist outdoors.

Each sensor module was coated with dust due to the dust test. The amount of dust in the dust cup only, i.e., not including dust in the flow tubes, in the new heater design was small, a pinch, approximately 20 milligrams -- roughly 10 percent of the mass of dust in the sampled air in the first dust test; a considerably smaller percentage was collected in the heater dust cup when employing the external screen inlet filter in the second test. The inlet tube to the dust cup is directed tangentially to produce cycloning of air by conservation of angular momentum as it rises into the eleven exit holes in the heater assembly above the dust cup. Evidently this action or stagnant volumes could be improved. The design intentionally allows for the possibility of including baffles to create stagnant volumes, impaction elements, filters, or other components in the dust cup. To retain simple design and to permit some particulate passage to enhance detection of particulate agents, baffles, etc. were not included in the dust cup for these dust tests.

After the second dust test, each inlet screen filter was coated, essentially clogged, with dust on the lower planar screen (see figure 40). The cylindrical screen and upper planar screens were relatively dust-free. The lower planar screen is oriented parallel to the top of the sensor module and is not enclosed on both surfaces but is under the rain cover of the screen filter as shown in the schematic sketch below. Thus the downwind walls of the holes in this screen serve as a myriad of dust impaction surfaces. The amount of dust in the heater dust cup was much less after this second dust test than that in the dust cup after the first dust test.

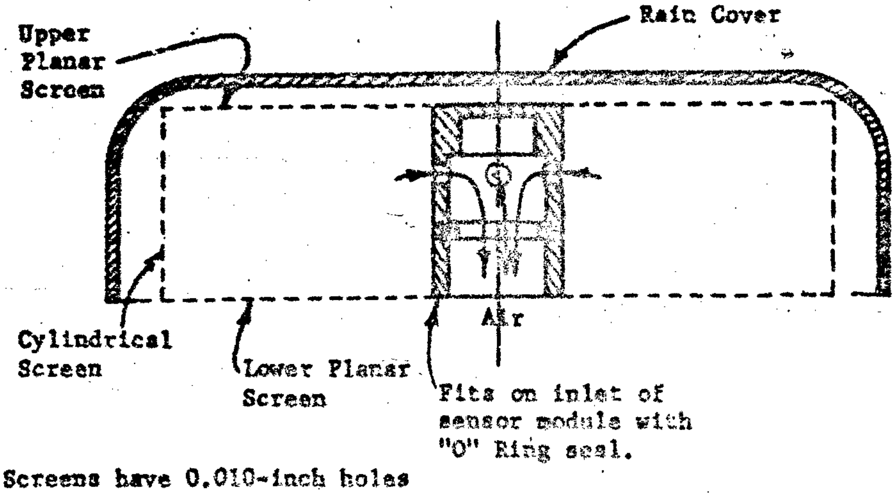



Figure 40. Schematic Drawing of the Inlet Screen Filter for the Sensor Module

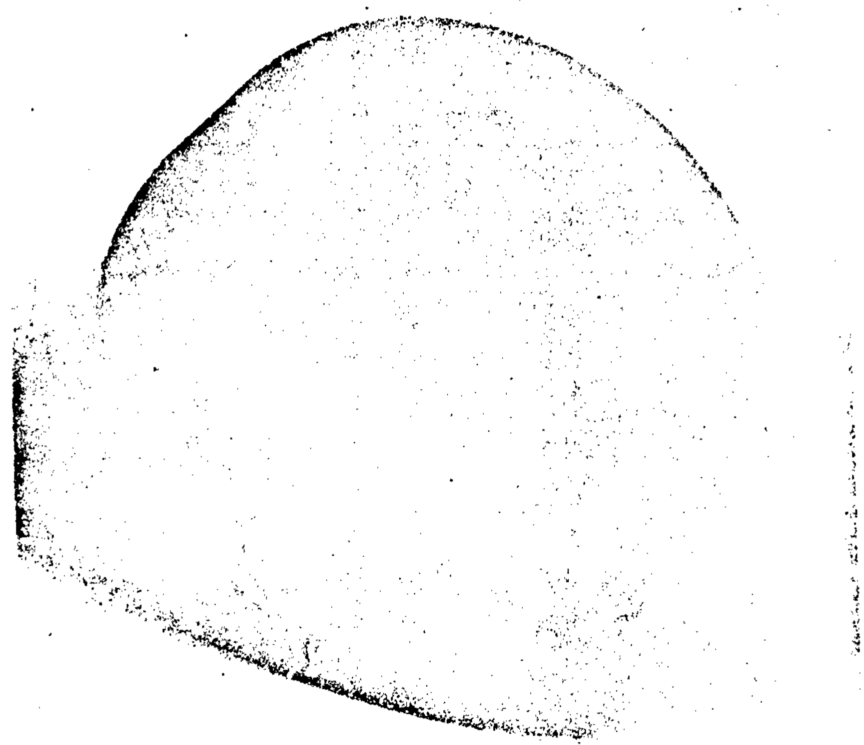


Figure 40a. The Inlet Screen Filter showing Lower Planar Screen

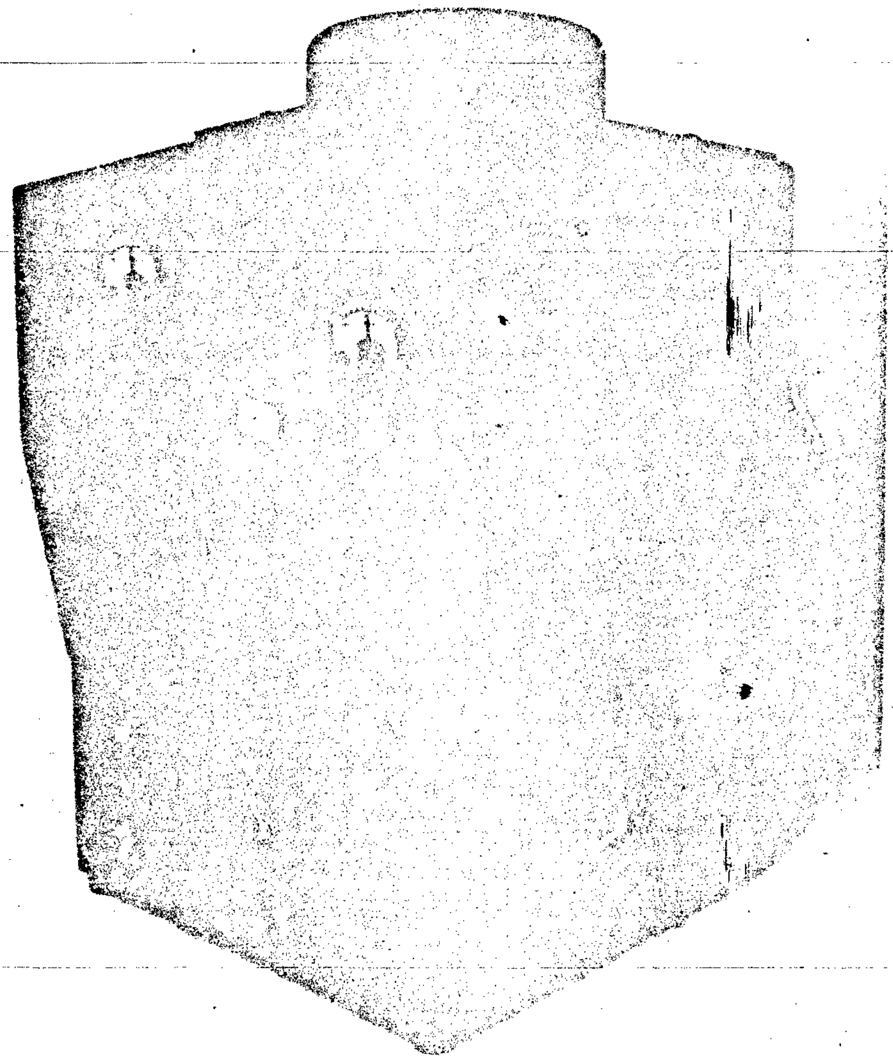


Figure 40b. The Inlet Screen Filter for Filtering Insects, Grass, etc. from the Air Stream as Mounted on an IDS Sensor Module

Table I below shows the change in flow and pressure drop through the sensor modules due to the dust tests. Comments on the eccentrics and diaphragms are discussed in more detail under Section VII.

TABLE I.

Flow and Pressure Drops for the Two Ionization Detector System Sensor Modules 4 and 7 as Related to Dust Tests

| SM No. | EVENT | FLOW, n ℓ/min BEFORE | FLOW, n ℓ/min AFTER | Δp, in. $H_2O$ BEFORE | Δp, in. $H_2O$ AFTER | COMMENTS |
|---|---|---|---|---|---|---|
| 4 with new heater design | Dust test no. 1 | 4.55 | 4.42 | 31.5 | 34.5 | After tests which included 140°F operation for 44 hours, it was noticed DB eccentric threw its grease. Dry eccentric bearings caused Δp fluctuations. Also, one silicone diaphragm was cracked partially through for 3/8 circumference at washer. |
| | Heater and cells cleaned | 4.39 | 4.47 | 33.8 ± 0.1 | 33.5 | |
| | Dust test no. 2 | 4.51 | 4.37 | 33.5 | 34.8 ± 0.2 | |
| 7 with original heater design | Dust test no. 1 | 4.72 | 4.59 | 21.3 | 25.7 ± 0.3 | DB eccentric threw its grease as above during 44 hours of 140°F operation. Dry eccentric bearings caused Δp fluctuations. |
| | Heater and cells cleaned | 4.61 | 4.79 | 26 | 23 | |
| | Dust test no. 2 | 4.81 | 4.6 | 22.8 | 22.4 ± 0.6 | |
| | Heater cleaned | | | | 21.0 ± 0.4 | |

The performance of the two sensor modules before and after the dust tests with and without readjustment of the units is presented in figures 41-44. Figures 41 and 42 present the results of the first dust test. The dust test increased the required concentration of malathion at alarm by a factor of ~ 2.1 for sensor module number 7 (figure 41) and ~2.4 for sensor module number 4 (figure 42). Cleaning the original design heater altered the response a bit more than cleaning the newer design heater but insignificantly in each case. Readjusting the flow and alarm levels (figure 42) nearly returned the response of the sensor module number 4 to original. The cause of the shift in the filtered air line due to the dust test is not fully understood at this time. It may be related to the location of the flow cell in the fourth downstream cell position where it would remain essentially free of dust particularly due to the preceding dilution filter. However, the usual, low S° cell signals on filtered air do not favor this argument.

The results of the second dust test (figures 43 and 44) were similar, with the required concentration enhancement factors being ~2.7. Cleaning the heaters improved the response somewhat more than in the first dust test. Cleaning the first two cells without disassembly using Freon 113 in an ultrasonic cleaner improved the response even more (figure 44). The filtered air line changed less in the second dust test than in the first. This factor plus the reasonably good performance of the system with 16 hours of dust-laden air ingestion with concentrations up to 10.6 g/m$^3$ at a sample flow of 4-5 liters per minute suggests that preconditioning the cells with dust may be a refinement -- a very small amount of dust on cell surfaces may produce the bulk of the alteration of the response characteristics.

## VI. SENSOR MODULE HARDWARE IMPROVEMENTS

In addition to the hardware improvements noted in the other sections, three other modifications were incorporated. These included rotating the fuse in the ac power supply, changing the type of connector used for the power and signal cord, and changing the type of feet used on the ac power supply.

The power fuse for the ac power supply is located inside the module. It is accessible when the power supply is removed from the sensor module through the top opening. In the MADS design the fuse was at right angles to the top opening and was difficult to replace. The bracket which holds the fuse was redesigned. The fuse is now mounted such that the fuse points toward the top opening. This modification was incorporated into the three modified units.

The power and signal cord of the MADS units utilized a Deutsch 9 pin connector. This type of connector was subject to damage under field type usage. Both these connectors were replaced with a more rugged Bendix connector. This required enlarging the cutouts in the panel of the ac power supply to accept the larger connectors and to replace both cords. This modification was incorporated into the three modified units.

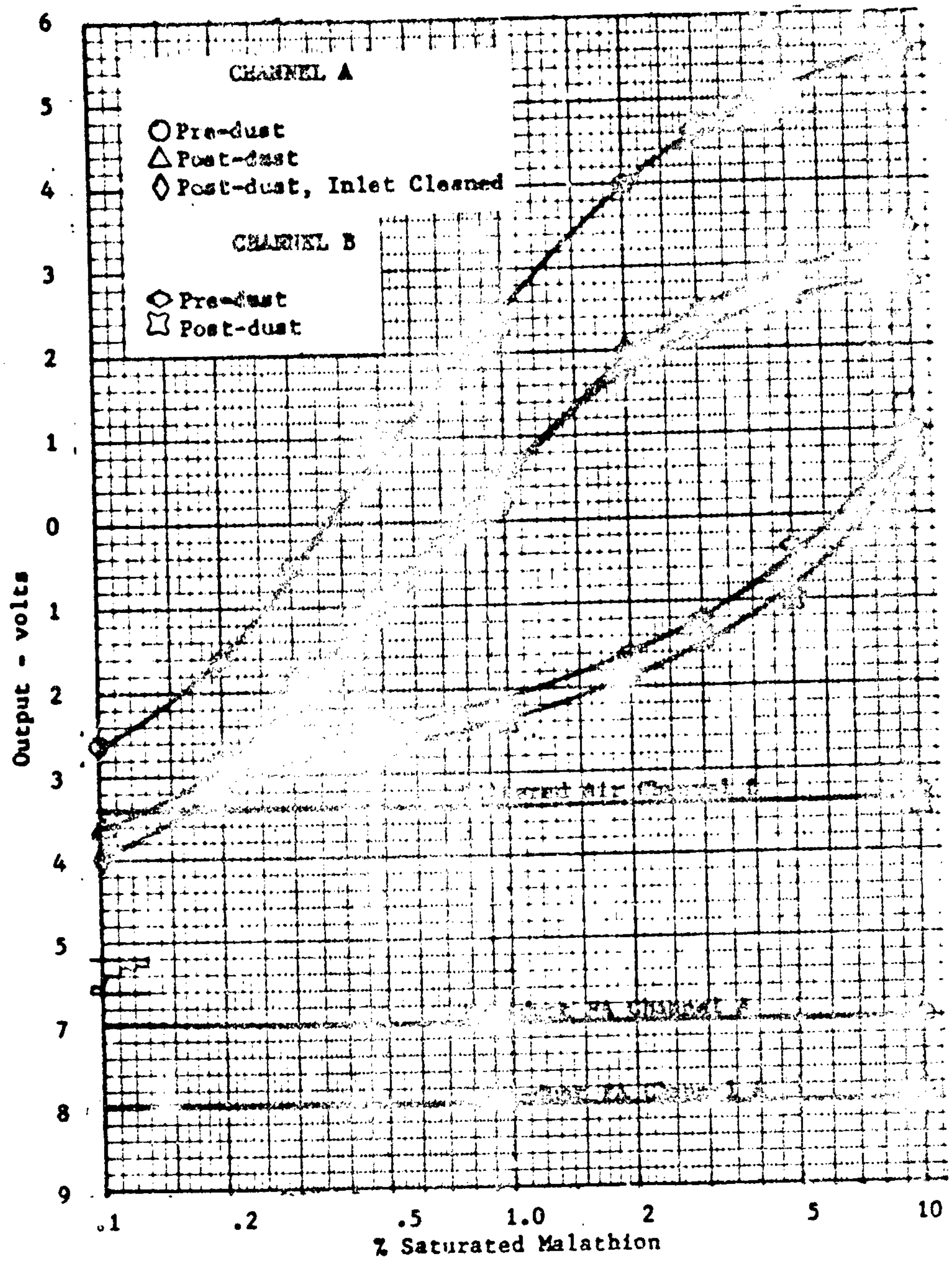



Figure 41. Ionization Detector No. 7 with the Original Heater Design without External Inlet Screen Filter: Response to Malathion Before and After the Dust Test. (First Dust Test.)

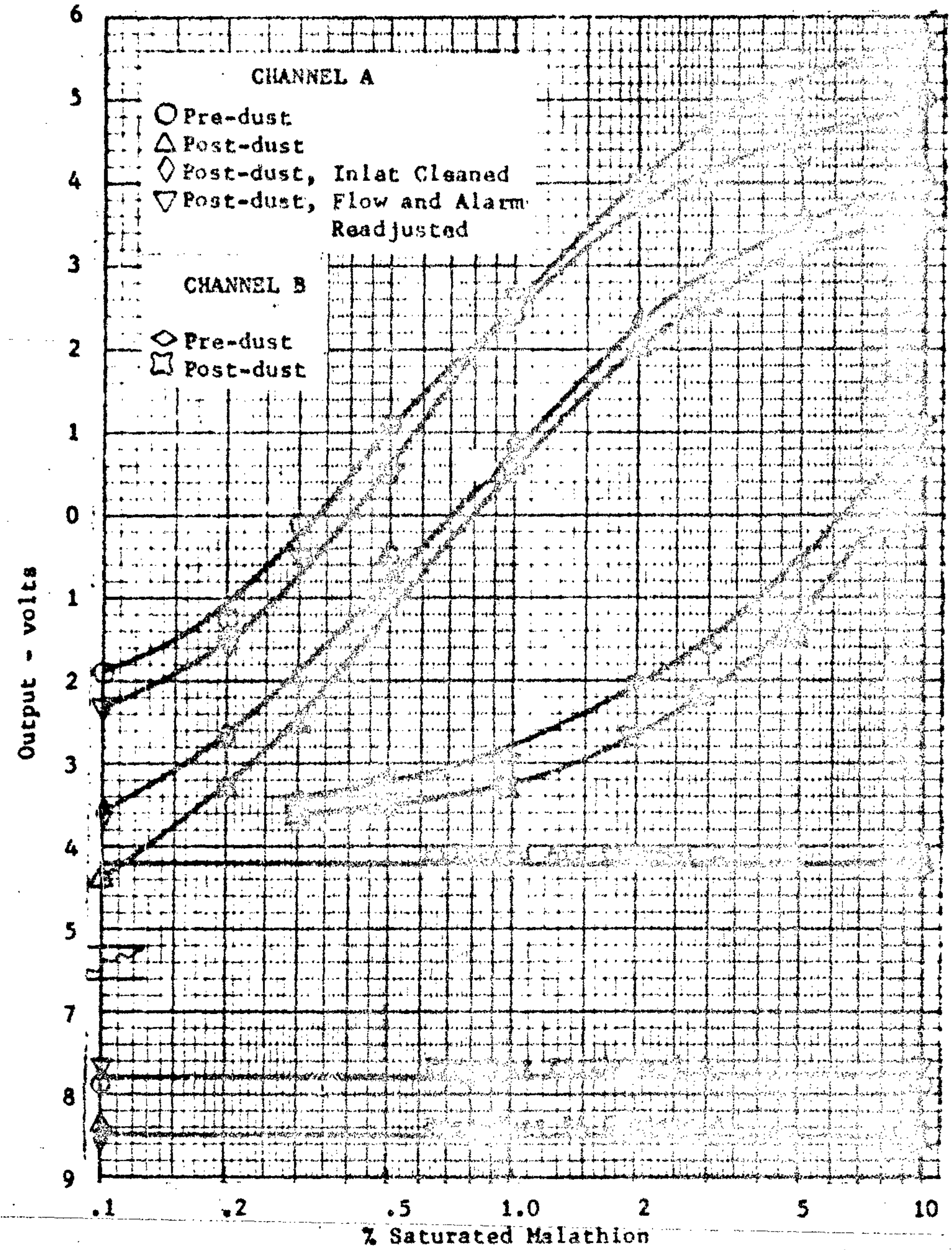



Figure 42. Ionization Detector No. 4 with the Revised Heater Design without External Inlet Screen Filter: Response to Malathion Before and After the Dust Test. (First Dust Test.)

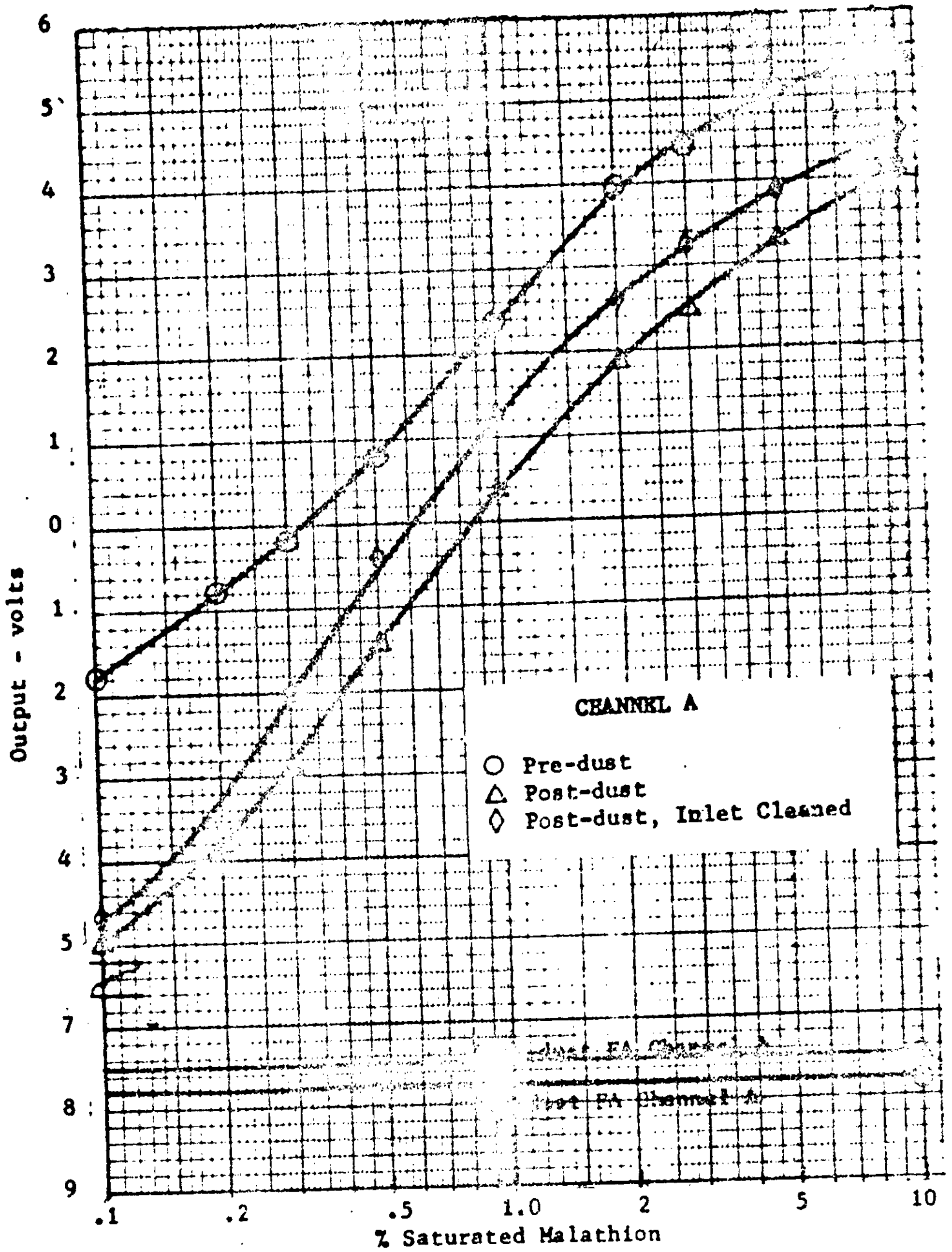



Figure 43. Ionization Detector No. 7 with the Original Heater Design with External Inlet Screen Filter: Response to Malathion Before and After the Dust Test. (Second Dust Test.)

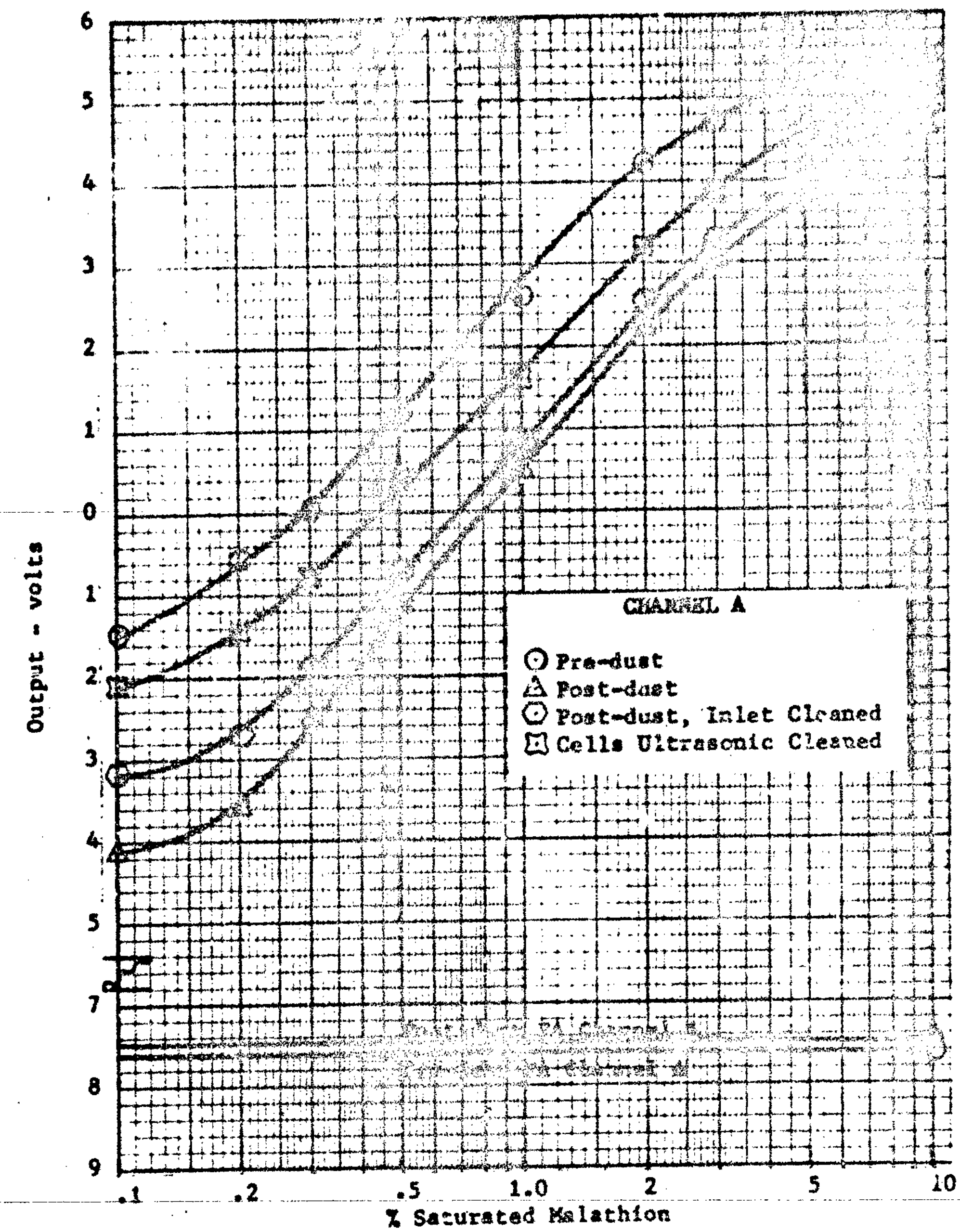



Figure 44. Ionization Detector No. 4 with the Revised Heater Design with External Inlet Screen Filter: Response to Malathion Before and After the Dust Test. (Second Dust Test.)

The rubber feet used on the ac power supply were made of molded rubber. With time some of the screws which held the feet to the chassis would pull through the rubber. To correct this problem, larger feet made of molded rubber with metal inserts are now being used.

## VII. MOTOR PUMP STUDIES

Motor pump improvement was the most important effort within the reported program. This section presents a description of motor pump problems encountered during the previous program, solutions to these problems during this IDS program, the results of tests, related system improvements, for example the use of a transistorized motor speed control, and an evaluation of other motor pump configurations. Understanding a problem leads to its solution, therefore the problems are described in some detail followed by a description of the solution of the deficiency.

### A. The Role of the Motor Pump

The motor pump is used to pump up to five normal liters per minute of air through the sensor module by reducing the pressure at the outlet of the sensor package by up to 40 inches of water column (three inches of mercury). This pair of numbers (5, 40) is not a requirement but a reasonable upper design goal or limit for the pumping situations encountered with the IDS. At the present level of IDS development, a typical pair of numbers of (4, 30).

At the self-imposed design limit, a motor speed of approximately 4000 r/min (one significant figure) would be required. For a goal of 10,000 hours mean time between failures (MTBF), the number of individual diaphragm flexes would be $5 \times 10^9$. To a first approximation this can be compared to expecting a fuel pump (for example) on an automobile to last for 500,000 miles when a life of one-tenth of this is common. The number of individual valve flexes and bearing revolutions would be similarly large. The goal (not requirement) to achieve 10,000 hours MTBF is a difficult one. Reduction of motor speed could help by a factor of about two only, but each factor of two is significant of course. Design improvement and selection of materials are other avenues toward extending the MTBF. Each of these has been pursued.

### B. Summary of Tests

Table II is a summary of tests of the motor pump assembly for the Ionization Detector System. The tests related specifically to motors but other components such as eccentrics, diaphragms, and valves were tested also. The table will be referred to in following presentations.

### C. Motor Pump Problems and Solutions

In the Multi-Agent Detector System (MADS) program, the motor pump had a starting requirement of -40°C (-40°F). For this reason Brailsford & Company, Inc. included many design changes into their TD-4X2 miniature brushless d-c

Table II Summary of IDS Motor/Pump/Eccentric Tests

| Test No.[1] | Motor | Eccentric | Time, Hours | Comments |
|---|---|---|---|---|
| 1a | Sperry P/N X003, Serial No. 3 | E2-P13 | 355 Test Completed | Test terminated at very early sign of motor bearing failure for diagnostic purposes. See results of Nov. 28 design meeting, Appendix B. |
| 2a | Sperry P/N X003, Serial No. 4 | E2-P13 | 1005 Test Completed | Motor bearings noisy. Eccentric fine but retired temporarily. See test no. 9a. |
| -- | Sperry P/N X003, Serial No. 5 | --- | -- | Returned to Sperry untested for rework per design meeting of Nov. 28. See test no. 5a. |
| -- | Sperry P/N X003, Serial No. 3 | --- | -- | Returned to Sperry untested because, after rework per Nov. 28 design meeting, it had radial play of motor shaft. Not received as of 8/20. |
| 2b | Sperry P/N X003, Serial No. 4 | E10-DB, E3-P13 at 1496 motor hours | 3218 as of 8/20 am | Motor of test no. 2a but reworked per Nov. 28 design meeting. Gray silicone L. diaphragm failure 350 to 730 hrs.[2] Gray silicone R. diaphragm failure ~885 hrs. Gray silicone L. diaphragm failure ~157 hrs. Replaced diaphragms with neoprene diaphragms from Edgewood Arsenal at 976 motor hours. DB eccentric failed due to bearing misalignment during 140°F ambient test for 44 hours. Replaced with E3-P13 at 1496 motor and E10-DB hrs. |

Table II Summary of IDS Motor/Pump/Eccentric Tests (Continued)

| Test No. | Motor | Eccentric | Time Hours | Comments |
|---|---|---|---|---|
| 5a | Sperry P/N X003, Serial No. 5 | E8-DB, E20-P02 at 1539 motor hours | 3906 as of 8/20 am | Motor reworked per Nov. 28 design meeting. Fully sealed bearings. DB eccentric with fully sealed bearings failed due to bearing misalignment during 140°F ambient test for 44 hours. Replaced with E20-P02 at 1539 motor and E8-DB hours. Replaced gray silicone diaphragms with neoprene diaphragms at same time; one silicone diaphragm was cracked. |
| 9a | Sperry P/N X003, Serial No. 6 | E2-P13 Used in 1a and 2a also. | 162 as of 8/20 am | In EMI tests. White silicone diaphragms. Preimproved valves. |
| -- | Sperry P/N X003, Serial No. 7 | -- | --- | Received June 4, 1973 |
| 12a | Sperry P/N X003, Serial No. 8 | E5-P02 | 1200 (est) as of 8/20 am | Delivered to Edgewood Arsenal May 1973. Neoprene diaphragms. |
| 3a | EAD DB15D-6, No. E-6 | E4-P13 | 5902 as of 8/20 am | White silicone L. diaphragm failure ~ 1300 hrs. |
| 4a | EAD DB15D-6, No. E-7 | E9-DB | 5499 as of 8/20 am | White silicone R. diaphragm failure ~ 1200 hrs. Inserted gray silicone diaphragm. White silicone L. diaphragm failure ~2700 hrs. Gray silicone R. diaphragm failure ~ 700 hrs. Replaced both diaphragms with neoprene diaphragms at 2867 motor hours. |
| 6a | EAD DB15D-6, No. E-8 | E11-DB | 1897 as of 8/20 am | Quiet at first but then ran noisy probably since diaphragms didn't form properly. Both gray silicone diaphragms failed within 150 hours. Replaced with neoprene diaphragms. |

Table II Summary of IDS Motor/Pump/Eccentric Tests (Continued)

| Test No. | Motor | Eccentric | Time Hours | Comments |
|---|---|---|---|---|
| 10a | EAD DB15D-6, No. E-9 | E7-P02 | 1200 (est) as of 8/20 am | Delivered to Edgewood Arsenal May 1973. Neoprene diaphragms. |
| 11a | EAD DB15D-6, No. E-10 | E6-P02 | 1200 (est) as of 8/20 am | |
| -- | EAD DB15D-6, No. E-11 | -- | -- | Received August 6, 1973 |
| -- | EAD DB15D-6, No. E-12 | -- | -- | |
| -- | EAD DB15D-6, No. E-13 | -- | -- | |
| 7a | Brailsford XTD-4X2 | Brailsford's new eccentric[3] | 783 Test completed | More powerful unit than TD-4X2, higher flow. Start-up problems. Plastic Scotch yoke seized outer bearing race causing yoke to hammer on eccentric cover. |
| 7b | Brailsford XTD-4X2 | Brailsford's new eccentric[3] | 2054 Test completed | Same motor and pump as in 7a. Boiled Scotch yoke to age it. Numerous failures to start. At end of test, no motor torque at zero rpm. Motor ran if started manually. Starter stuck. One white silicone diaphragm was cracked. 7a + 7b hrs: 2837. |
| 8a | Brailsford TD-4X2 | Brailsford's new eccentric[3] | 3924 as of 8/20 am | Failed on start only once, at 232 hrs. |

1 Except as noted all pumps had visually selected improved valves: 0.010-inch thick instead of 0.007-inch thick, fabric re-inforced silicone with higher thread count. $MoS_2$ was used to coat diaphragm-washer assemblies and all adjacent surfaces contacting the diaphragms.

2 Hours associated with diaphragms are diaphragm hours to failure, not motor hours.

3 Different eccentric bearing assembly, same eccentric and plastic rod assembly.

doubleacting diaphragm blower (which was then designated TD-4X2H, H for Honeywell) to meet this goal but which, as experience subsequently showed, resulted in a motor pump with a far from adequate MTBF. These changes not only decreased the MTBF but also decreased the efficiency. Silicone oil for motor bearings, silicone valves, silicone diaphragms, and motor electronics revisions were incorporated to meet the low temperature starting requirement. Seals on bearings were not employed since it was found that the motor pump torque at the required motor speed was inadequate.

Changing from silicone oil to a nonsilicone grease (Humble Oil's Andok C) for the motor bearings increased their life from the order of a few tens of hours to the order of a few hundreds of hours. This was still too short, yet this relatively small life extension unveiled other problems which included,

- Other motor bearing failures
- Eccentric problems -- bearing failures, shaft wear, Scotch yoke impact
- Start-up problems
- Motor electronics failures
- Diaphragm failures
- Valve failures
- A decrease in flow with time

1. Motor Bearing Failures -- The most fundamental motor pump failure modes involved failure of the eccentric bearings and the motor bearings, especially that one at the output end of the shaft. It is believed that these failures were due principally to impact loading of the bearing races due to excessive radial play in the bearings and not due to pump loading or to imbalance loading per se. Calculations indicate this to be probable.

First, consider a pressure drop of 30 to 40 inches of water through the IDS. If we consider the diaphragm to have a pumping area on the order of three-quarters of a square inch, the maximum pumping force $(F_p)_{max}$ on the bearing would be

$$
\begin{aligned}
(F_p)_{max} &= A\,\Delta p_{max} \\
&= 0.75\,[\mathrm{in}^2] \times (30 \text{ to } 40)[\mathrm{in}\ H_2O] \times \frac{1}{407}\left[\frac{\text{atmospheres}}{\mathrm{in}\ H_2O}\right] \\
&\quad \times 14.7\left[\frac{\mathrm{lb_f/in}^2}{\text{atmospheres}}\right], \quad [\mathrm{lb_f}] \qquad (1) \\
&= 0.81 \text{ to } 1.1,\ [\mathrm{lb_f}]\,.
\end{aligned}
$$

where the abbreviation $lb_f$ denotes a pound-force.

The mass of the TD4X2H connecting rod, two diaphragms, four diaphragm washers, two diaphragm screws, and two eccentric bearings is about seven grams. Some of the mass of the eccentric shaft and some of the seven grams of mass mentioned can be and is countered by removing mass from the eccentric assembly. Consider the force necessary to accelerate an imbalance of seven grams, a case worse than necessary. For a motor speed of 3000 to 4000 rpm, the angular velocity ($\omega$) is given by

$$\omega = (3 \text{ to } 4) \times 10^3 \text{ [rpm]} \times 2\pi \left[\frac{\text{(radians)}}{\text{revolution}}\right] \times \frac{1}{60} \left[\frac{\text{min.}}{\text{sec.}}\right] \tag{2}$$

$$\approx (3 \text{ to } 4) \times 10^2 \text{ , [(radians)/second]}.$$

The linear displacement (x) of the connecting rod is given by

$$x = e \sin \omega t \text{ ,} \quad \text{[cm]} \tag{3}$$

where e is the eccentricity (= 1/16 inch), [cm].

The magnitude of the maximum linear acceleration ($\ddot{x}_{max}$) is given by

$$\ddot{x}_{max} = \left| - e\omega^2 \sin \omega t \right|_{max} = e\omega^2 \text{ , [cm/sec}^2\text{]} . \tag{4}$$

The maximum force required to accelerate the seven-gram mass considered is

$$\begin{aligned} F_{max} &= m\ddot{x}_{max} \text{ , [dynes]} \\ &= me\omega^2 \\ &= (1.00 \text{ to } 1.78) \times 10^5 \text{, [dynes]} \\ &= (0.225 \text{ to } 0.401) \text{ , [lb}_f\text{]} \\ &\approx 0.3 \text{ , [lb}_f\text{]} . \end{aligned} \tag{5}$$

Comparison of equation 5, which represents a worse-than-actual case, with equation 1 indicates the pumping load to be the major load.

One experiment with a different motor brand (Eastern Air Devices, Inc.) in the earliest stages of development before this program resulted in an elongation of the bore in the aluminum end plate of the motor which retained the outer race of the bearing on the output shaft of the motor. The bore was elonga-

ted by several thousandths of an inch. The motor manufacturer explained that the bearing manufacturer recommended a large radial clearance in the bearing to tolerate the pumping loads of about one pound-force. As shown, except as noted below, this was an improper recommendation but one which illustrates the point of view. A large pumping force such as a one-pound force plus excessive radial clearance resulted in impact peening or Brinelling of the bearing races. The effect was enhanced by the long moment arm existing between the connecting rod mounting point on the eccentric assembly and the bearing on the output shaft of the motor. The long moment arm amplified the radial clearance in the bearing allowing the eccentric to turn through a larger angle before removing the radial clearance. Associated with this larger angle was a higher component of the linear velocity of the eccentric for a larger impact force on the bearing when the clearance was removed at impact. On the other hand, a larger radial play would result in a larger bearing contact angle which for properly preloaded bearings would result in a bearing system capable of tolerating greater loads.

Since E.A.D., Inc. utilizes a satisfactory method of preloading the motor bearings, there remains a question as to why this failure occurred. Even when first operated, the motor pump hammered. Perhaps preloading was not accomplished. Perhaps the outer race retaining bore was too large for the outer race diameter, i.e., out of specification since their specified dimensional tolerance was satisfactory, to thereby introduce another source of radial play. The manufacturer changed the end plate material to stainless steel. Whatever the cause, the problem has never reoccurred.

2. <u>Solution to the Motor Bearing Failure Problem</u> -- The solution to the motor bearing problem was not separated from other problems. To eliminate impact loading of motor bearings, sources of play in the rods, eccentric bearing, and motor bearings had to be eliminated. Also the life of these motor driven components had to be extended. To accomplish this, a new rod and eccentric assembly was designed and fabricated as discussed in a subsection below.

Analyses and experience indicated motor bearing lifetimes of 10,000 hours should be possible in the IDS application for properly lubricated bearings if impact loading and contaminants could be eliminated from the bearing environment. The motor bearings were shielded bearings and the eccentric bearings were open bearings, typically. With respect to the introduction of contaminants, shielded bearings must be treated as open bearings. Thus, assuming the interior of a motor housing to be clean, the bearing on the output shaft should have an outer seal. The eccentric bearings should have double seals. But seals add drag torque to bearings; however, sealed bearings were considered in the IDS application.

A single, quality bearing fabricator, MPB Corp., was selected to work with Honeywell on the problem. Motor bearings were examined by Honeywell and by MPB Corp (see appendix A). The set of specifications to solve the problems included the following which were applied to motors made by Eastern Air Devices, Inc. and Sperry Rand Corp. Each bearing was specified to contain an MCK ball retainer which is nonmetallic, basically Teflon, to avoid metallic wear debris. The lubricant was changed from Humble Oil's Andok C, a good grease, to Mobil-

grease 28, 20-30% fill. Andok C grease has better low temperature channeling characteristics but Mobilgrease 28 experimentally performs better above 150°F and otherwise appears to be superior in this IDS application. The bearings were specified to be fully sealed. Shields, unless of the multishield or labyrinth type, cannot exclude debris from the bearings. The radial play of each bearing was specified to be 0.0005 to 0.0008 inch; then the bearings were to be preloaded, as a pair, to one pound. The specified play increases the bearing contact angle to increase the tolerance of the bearings to physical shock by properly supporting the weight of the normally vertical motor shaft and armature, a phenomenon analogous to the tight rope problem studied in physics. The inner races were specified to be carefully Loctited to the shaft as were any spacers to avoid wear debris. The outer races were also specified to be Loctited to their respective bores if preloading is accomplished with a one-pound dead weight. With wave washer or similar preloading, outer race to bore Loctiting was not required if the bore is precision machined to $0.5000 {}^{+0.0002}_{-0.0000}$ inch. Similar precision fabrication was permitted for the bearing bore at the output end of the shaft for dead weight preloading. With the dead weight and Loctiting preloading technique, after full use the total end play of the shaft was specified to be 0.0005 inch when applying a longitudinal load of 0.5 pound-force to and fro on the shaft.

Success of these specifications seems highly probable since no bearing failures after several thousand hours on several units occurred in motors built to these specifications during the reported IDS program. For a summary of tests, see table II above.

3. Eccentric Problems -- In the design by Brailsford & Company the inner races of the eccentric bearings could rotate on the eccentric shaft. While this has the advantage of more evenly distributing the load on the inner races often severely wore the shaft. In fact, occasionally eccentric shafts were completely severed by this process. Even before such a catastrophic failure, wear debris could enter the eccentric bearings to shorten bearing life. An E-clip held the two eccentric bearings onto the eccentric shaft and rotated relative to the outer race and also relative to the inner race since as explained above the inner race could rotate on the eccentric shaft. Furthermore, the E-clip extended diametrically to overlap the outer race, so relative motion of the E-clip and either race could also be a source of wear debris and shortened bearing life. The eccentric bearings were completely open bearings. Hence contaminants and/or wear debris could enter a bearing to enhance rotation of the inner race of the eccentric shaft, to create more wear debris, etc. Instances of an E-clip wearing its way out of its retaining groove were common. The outer bearing could then slip off the eccentric shaft if the shaft was not worn so badly that it contained the bearing. Failure was often absolutely total. Radial play in the bearings and Scotch yoke resulted in impact loading of the system to cause other failures.

Brailsford and Company employs a Scotch yoke to drive the diaphragms, figure 45. The outer races of the two flanged eccentric bearings roll in the slot in the plastic Scotch yoke. The flanges of the bearings confine the yoke axially. For the eccentric bearing to roll along one side (the pumping side) of the slot

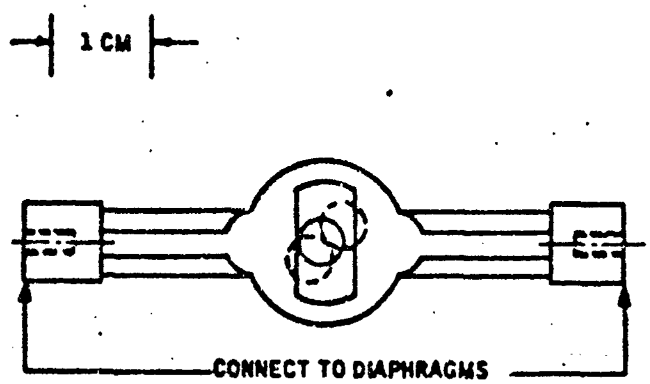



Figure 45. Brailsford Version of the Scotch Yoke Showing Schematically the Eccentric Bearing (Solid Circle) in a Proper Position and in Two Positions (Dashed Circles) after Denting of the Plastic

in the Brailsford Scotch yoke, there must be clearance in the slot so that at the other end of the diameters of the eccentric bearings the races do not slide on the wall of the slot. When pumping changes to the other diaphragm (180° away), the clearance (several thousandths of an inch when new) is traversed by the outer races which impact the plastic Scotch yoke. This impact dents the plastic to result in increasing bearing impact as well as a reduction of the pumping stroke and therefore a reduced flow.

4. Solution to the Eccentric Problems -- To solve the eccentric problems Honeywell designed and fabricated two eccentric and rod assemblies for use on the IDS motor pump assembly to replace Brailsford's version of the Scotch yoke. (Drawings of the designs were sent to Brailsford & Company who did not implement them. They did revise their eccentric bearing, however. The units are now in test.) Both designs employ magnesium rods. The P13 eccentric assembly employs two bearings with only 0.0001 inch to 0.0003 inch of radial play (P13). The bearings are attached to the rods shown in figure 46 with Loctite 601 (see appendix A). The inner races are kept from turning on the eccentric shaft by two washers, a hexagonal socket head cap screw, and the use of Loctite 601. The inner race spacer assures that the connecting rods do not contact to cause wear debris. The washers are sufficiently small in diameter that they cannot contact the outer races of the eccentric bearings. The DB preloaded eccentric bearing assembly is shown sketched in figure 47. The unit employs four bearings in the form of two duplex pairs of preloaded bearings, DB ground. This eccentric design eliminates all of the radial play in the bearings by preloading. Negative factors with the DB eccentric are that it is complicated, therefore difficult to Loctite, and expensive. Fully sealed bearings (ZZ) with molded, glass-filled, Teflon retainers (MCK) and with 20%-30% filled by plating Mobilgrease 28 (LYF-231) from MPB Corp. are utilized. By removing the outer bearings and shortening the eccentric shaft, the P13 eccentric assembly is generated in one's mind. The P02 eccentric assembly is similar to the P13 assembly except that the radial play is 0.0000 to 0.0002 inch with the additional specification that the bearings not be internally tight. This specification is necessary because of the zero lower limit on the radial play. P02 eccentrics were supplied on the units delivered under this contract.

The conditions for dynamic balance of the eccentric were calculated excluding balancing of couples. To balance couples would require a major redesign of the eccentric to include, perhaps, another main bearing outboard of the motor and eccentric assembly; such a major modification did not seem warranted since the imbalance forces are not large. Single crank pumps, such as the Brailsford TD-4X2H, cannot be perfectly balanced. The effective direction of the residual imbalance can be controlled by introducing additional imbalance. The latter effect is employed on single cylinder engines in motorcycles, for example, where vertical vibrations are more annoying to the driver than longitudinally horizontal vibrations. It is unlikely that such techniques will be required for the IDS motor pump assembly and if they be, it would be better to redesign to the two-crank configuration with an outboard main bearing mentioned above. An additional advantage of the outboard main bearing would be to reduce the load on the output bearing of the motor.

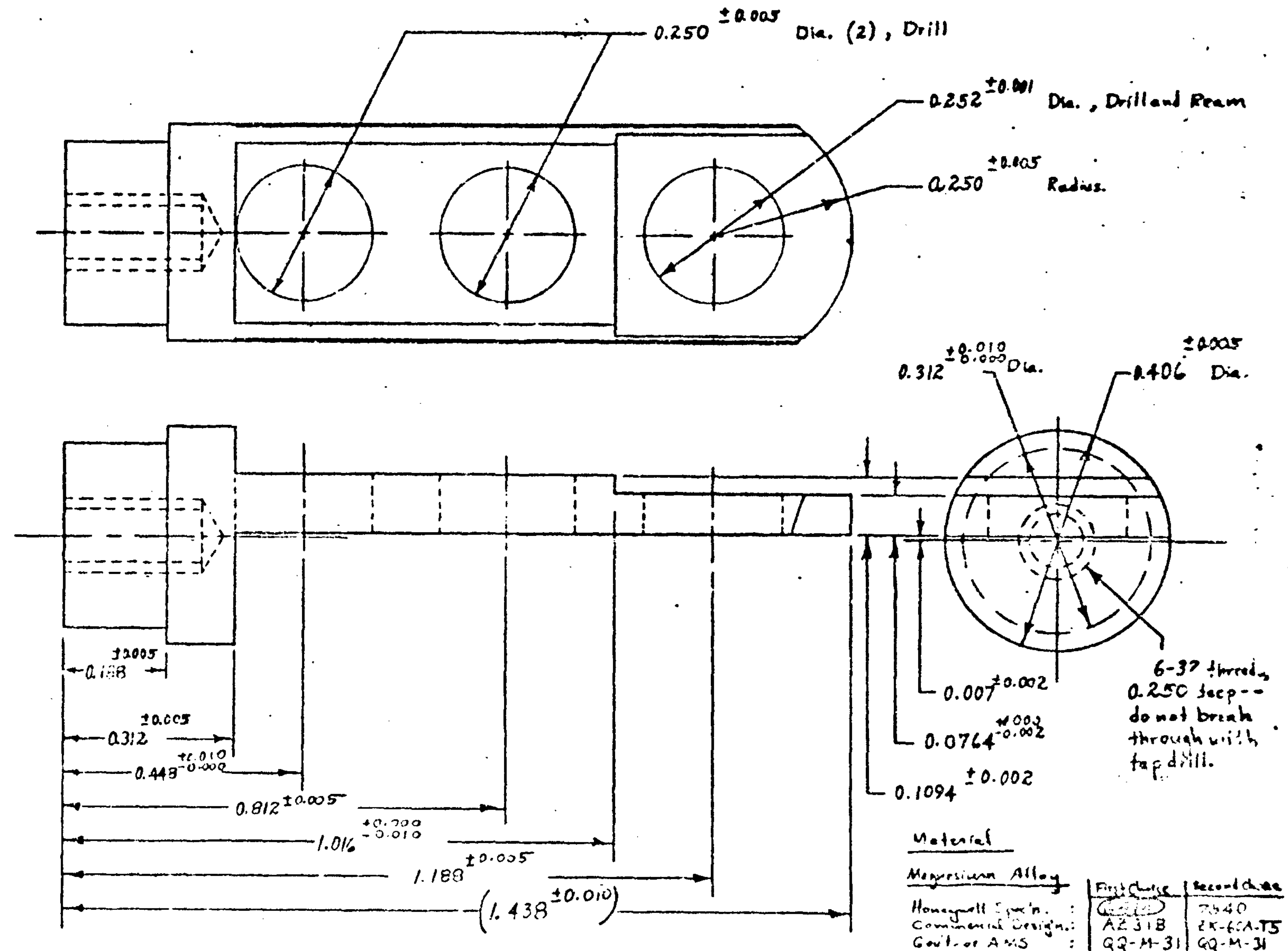



Figure 46. IDS, Connecting Rod for Modification of Brailsford TD-4X2H Motor/Pump

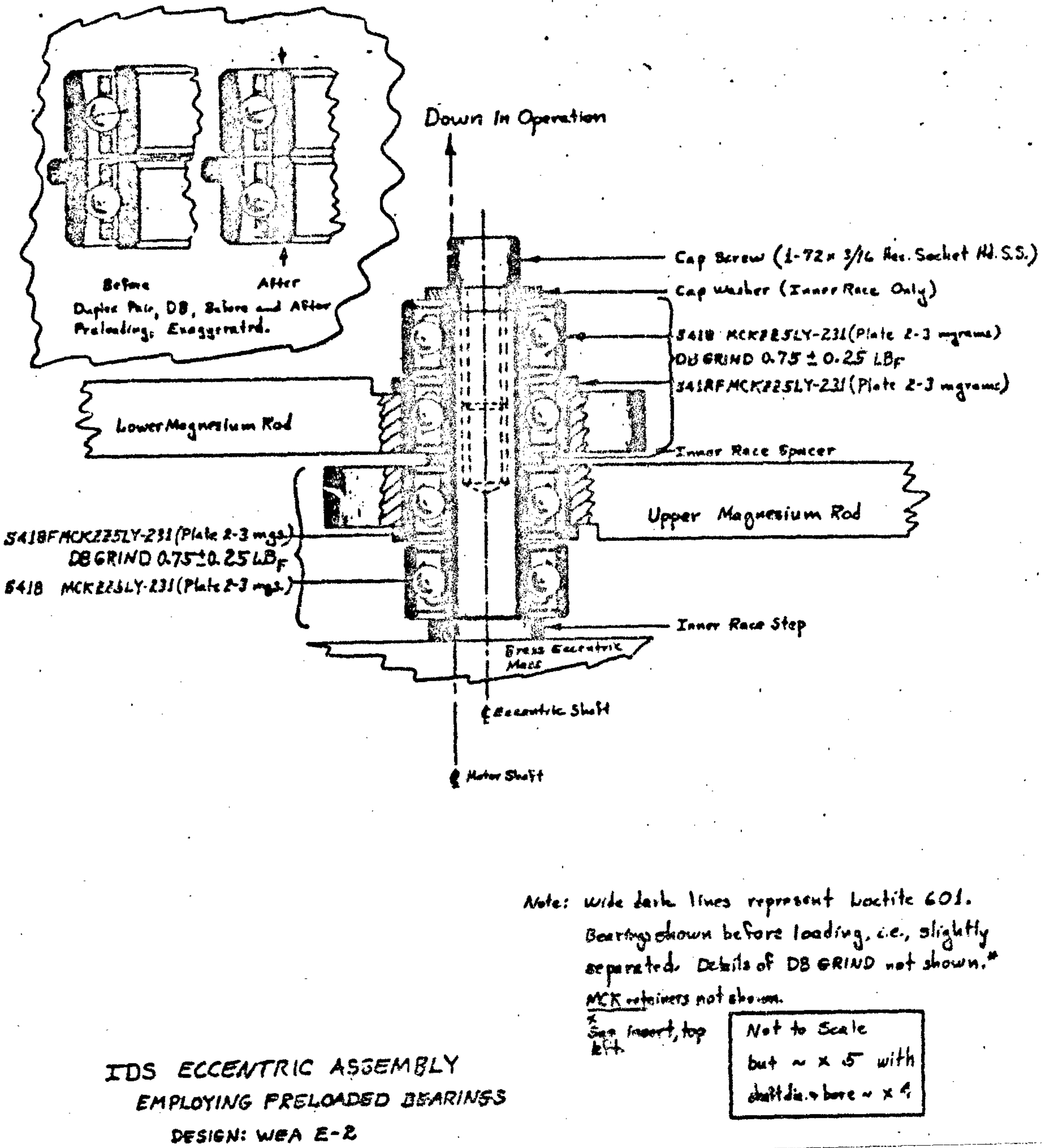



Figure 47. An Eccentric/Rod Design

The P02 and P13 eccentric/rod assemblies appear to have solved the problems described above. There has never been a P02 or P13 eccentric/rod failure before or during this program even after several thousand hours on each of several units. See test results above, table II.

When two different operating sensor modules were subjected to the upper temperature environment limit of 140°F (60°C), the DB eccentric in each failed in the sense that bearing noise became evident: E10-DB at 1496 hours and E8-DB at 1539 hours. An examination of the worse one (E10-DB) by MPB Corp. indicated the bearings were good but they were out of grease. Both of these units went through the 44 hours of 60°C (140°F) ambient during the two dust tests. Dust did not cause the problem. Apparently, according to MPB personnel, the 60° °C temperature at the eccentric caused the grease to migrate through the bearing seals at their retainers. This phenomenon is believed by MPB to be due to the revolving of the eccentric bearings which centrifuges the "hot" grease through the minute clearances among the outer race, seal, and seal retaining ring. This leakage problem could be eliminated by special attention to the method of capturing the seal -- spinning metal onto the seal to retain it might be an answer, another might be a bead of epoxy after cleaning the annulus of grease. Also, Loctite makes compounds which cure without degreasing surfaces. Perhaps a carefully applied bead of such a Loctite would seal the seal at its nonsliding outer circumference. MPB Corp. is currently examining this problem and will supply Honeywell with bearings with "sealed seals" for testing. If it exists the grease centrifuging problem would be a fundamental problem which would have been associated with all former open eccentric bearing failures. It could be eliminated from concern as a potential cause of eccentric bearing failure by the use of sealed seals.

Honeywell personnel skilled in the use of instrument bearings do not agree with the MPB analysis. Mobilgrease 28 at or considerably above 140°F is not thin. Also Honeywell makes gyros in which the outer races of bearings in the inertia wheel rotate at 24,000 rpm with Mobilgrease 28 and perform properly for 50,000 hours. A rough calculation shows the centripetal force per unit mass of retained grease to be ~60 times greater for the gyro than for the IDS eccentric. The DB brass eccentrics discolored as though they became hot. MPB said the bearing components did not exceed their critical temperatures to discolor. The DB assemblies were not smooth, even when new. Honeywell personnel suggest therefore that the DB pairs--which for this application were specially DB ground due to the unusual method of applying the DB load--were never good.

A further examination by Honeywell of these two DB eccentrics showed bearing misalignment of every bearing (eight) to be the cause of the bearing failures. Such misalignment would cause the bearings to run warmer than normal. At a room temperature of 140°F (vs. the usual 75°F) the heat transfer from the bearings could be reduced sufficiently to heat the brass eccentric to the point of discoloration. The set up for fabrication of the brass eccentric mass is such that misalignment would not be introduced by this component. MPB personnel claim they DB ground the bearings true. The source of the misalignment has not yet been demonstrated.

For specific test details, see a summary of tests in a subsection above, table II.

5. <u>Motor Start-up Problems and Solutions</u> -- The Brailsford & Company motor employs brushes and a commutator for starting after which the motor converts to d-c brushless operation by centrifugally moving the commutator pins inward away from brush contact at 2000 to 2400 rpm and running on an internal electronic oscillator commutator. Start-up problems occurred especially with warm motors (~140°F = 60°C) due to bearing failures, centrifugal switch hang-up, dirty commutator pins and brushes, electronic failures, and warpage of the plastic Scotch yoke. Failed bearings sometimes locked the rotor but also generated debris which contaminated the pins and brushes to cause poor electrical contact.

Start-up problems may have been increased by operating the Brailsford and Company motor pumps at elevated temperatures (50-60°C) for extended periods of time. Oxidation of the pins and brushes could have resulted in insulating surface compounds. A start-up test at Brailsford & Company (with a million plus starts and stops) did not confirm our start-up failure frequency data. The difference may have been due to the time interval between starts as it relates to the formation of surface tarnish films or other films. In a different situation, one start-up failure Brailsford & Company did encounter was traced to a bit of resin between a pin and brush. Evidently the resin was debris from soldering operations on the motor. The pins (90% silver, 10% copper alloy) and brushes (75% silver, 25% copper alloy) are gold plated, primarily for purposes of storage. Possibly after a few starts the gold wears through in the contact areas to permit insulating oxidation (due to sulfur) layers to form. In particular this could be true if for any reason the motor ran below the starter engagement speed of 2000-2400 rpm. Alternatively, plasticizer from the plastics may have condensed upon the contacts. Cleaning the contacts with Freon 113 often worked. Substitute noble alloys for the pin and brush assembly were selected to eliminate the potential oxidation problem but no action was taken. Multi-element brushes would introduce redundancy to possibly circumvent the problem. Burrs on the centrifugal starter weights of the Brailsford & Company motor were found to catch in the plastic centrifugal switch housing. Brailsford & Company buffed their parts which temporarily solved this problem. Subsequently a new die was fabricated to produce the parts to correct the situation.

By cooperation between Honeywell and Brailsford & Company, the electronic circuit was modified to reduce electronic failures, but they have not been eliminated at this writing.

Two motor pump units were reconditioned by Brailsford & Company for life tests during this reported [illegible] program. The Scotch yoke warped on one unit (test no. 7) to seize the outer race of the eccentric bearing. The motor would not start without hitting the sensor module hard with the palm of a hand. Then the unit hammered due to the capturing described by driving the yoke laterally into its cover. Brailsford & Company now boils the plastic yokes in water to age them to apparently solve this problem. Numerous other start-up failures occurred with this unit which finally would not start. It was sent to Brailsford & Co. for analysis at [illegible] total hours. The other unit has had one start-up failure.

Most recently Brailsford & Company was considering an optical commutator to reduce start-up problems. Honeywell suggested they discuss it with Edgewood Arsenal since such a commutator might not pass nuclear radiation tests. Brailsford & Co. will examine the returned motor to attempt to solve the non-start problem.

Brailsford & Co.'s examination of the motor pump from test no. 7 revealed that one of the starter plates jammed in the noncontacting (running) position. The plate was freed and the assembly worked fine. The starter was disassembled and inspected. One of the two starter plates appeared to have been cemented to the starter cover plate, possibly due to the effect of elevated operating temperature on the uncured vinyl coating applied to the electronic network package which is in close proximity to the starter. The crank bearing was inspected and found to be exuding grease, some portion of which was discolored indicating partial breakdown of the lubricant. The bearing was in good condition with sufficient good grease remaining between the shields. One silicone (white) diaphragm had a series of cracks and was approaching failure.

For the IDS program reported, numerous problems associated with the Brailsford & Company motor pump assembly were circumvented by careful attention to detail by Honeywell to bearings, eccentric/rod design, and electronics. These improvements were included into units employing Eastern Air Devices and Sperry Rand motors with Brailsford & Company pumps. Development of Brailsford & Company motors continued on a low priority basis.

Start-up problems were not eliminated from the Brailsford & Company motor during this IDS program.

6. Diaphragm Failures and Solution -- Diaphragm lifetimes were related to material composition, the method of applying adhesive to the diaphragm washer, pump design, and the nature of surface lubrication.

The silicone used for diaphragms was a commercial formulation which we now know is subject to variations. Two purchases of silicone diaphragms were employed in the IDS tests--one batch was white, the other was off-white, called gray. As indicated in table III the gray diaphragms had a life from $<150$ to $>1539$ hours with a mean life of $\sim 700$ hours. White silicone diaphragms were much better with lifetimes varying between 1300 to $>5902$ hours with a mean life in excess (since many are still running) of 2700 hours, in excess of 2900 hours if 7a-7b and 8a in table III had white silicone diaphragms as thought. These numbers exclude test 9a with its very few hours as of August 20.

Silicone diaphragms were originally employed to favor passage of the -40°F (-40°C) cold starting temperature requirement. Recent cold start tests reported elsewhere indicated neoprene diaphragms would be satisfactory. The short life of silicone diaphragms necessitated changing to neoprene diaphragms. As of August 20, em, none of the 14 neoprene diaphragms had failed in over 25,000 total hours of operation for an average time per diaphragm of 1800 hours. The neoprene used for these diaphragms is a special, well-controlled formulation developed at Edgewood Arsenal for pump diaphragms. Brailsford

Table III. Diaphragm Performance

| Test No. | Material and Pump Side | Status, (Hours) | | |
|---|---|---|---|---|
| | | Failed | Unfailed | |
| | | | Test Completed | Test Continuing as of 8/20/73 am |
| 1a and 2a | White silicone[1], L & R | - | 1560 | - |
| 2b | Gray silicone,[2] L | 350 to 730 | - | - |
| | Gray silicone, R | 885 | - | - |
| | Gray silicone, L | 157 | - | - |
| | Neoprene, L & R | - | - | 2242 |
| 3a | White silicone, L | 1300 | - | - |
| | White silicone, L | - | - | 4602 |
| | White silicone, R | - | - | 5902 |
| 4a | White silicone R | 1200 | - | - |
| | Gray silicone, R | 700 | - | - |
| | White silicone, L | 2700 | - | - |
| | Neoprene, L & R | - | - | 2632 |
| 5a | Gray silicone, L(?) | 1539 | - | - |
| | Gray silicone, R(?) | - | 1539 | - |
| | Neoprene, L & R | - | - | 2367 |
| 6a[3] | Gray silicone, L | 150 | - | - |
| | Gray silicone, R | 150 | - | - |
| | Neoprene, L & R | - | - | 1747 |
| 7a[4] & 7b[4] | White silicone, L(?) | 2837[6] | - | - |
| | White silicone, R(?) | - | 2837 | - |
| 8a[4] | White silicone, L&R | - | - | 3924 |
| 9a | White silicone, L & R | - | - | 162 |
| 10a[5] | Neoprene, L & R | - | - | 1200 (est.) |
| 11a[5] | Neoprene, L & R | - | - | 1200 (est.) |
| 12a[5] | Neoprene, L & R | - | - | 1200 (est.) |

[1,2] Silicone diaphragms were obtained under two purchase orders. Their colors were different. The first set were white, the second gray. The gray diaphragms had unusually short lives.

[3] This unit was taken to England for demonstrations.

[4] These units were reconditioned by Brailsford & Co. for controlled life tests

[5] These units were delivered to Edgewood Arsenal in May 1973.

[6] One diaphragm was cracked at 2837 hours.

& Company considers the silicone diaphragm to have a life approximately one-half that of a neoprene diaphragm and considers the life of a neoprene diaphragm to be 2500 to 5000 hours. With the special precautions discussed next which were taken by Honeywell, the neoprene diaphragm lives may be even longer.

The Brailsford & Co. two-diaphragm pump is asymmetric. As part of the pump improvement the pump was centered with respect to motion of the two diaphragms. Due to this it was possible to place the diaphragms closer to the pump heads to reduce the clearance volumes. The pumps were quieter with this modification probably due to the instantaneously and certainly proper forming of the diaphragms with less diaphragm slap. (Diaphragms must be "formed" for the vacuum or pressure mode of pump operation. IDS employs the vacuum mode.) Furthermore, the diaphragm and surrounding plastic parts were coated with $MoS_2$ powder for improved lubrication of the diaphragm.

Diaphragms are supplied by Brailsford & Co. with the outer washer attached by adhesive. Honeywell noted that adhesive commenced to extend onto the rounded edge of the washer over an angle of up to 180° and sometimes appeared to liquify. The adhesive and the method of applying the adhesive had been changed by Brailsford & Co. from brush to spray. The adhesive on the rounded edge of the diaphragm washer collected $MoS_2$ and other material to form a ridge. In a test, the ridges formed and silicone diaphragms were scarred by these ridges in less than 45 hours of operation. Brailsford & Co. is again applying the original adhesive by brush to keep the rounded edge of the washer free of adhesive.

Honeywell believes the pump and diaphragm changes presented above plus the effort to reduce motor pump speed to be the best known approach to solve the diaphragm failure problem.

7. Valve Failures and Solution -- Numerous valve failures occurred prior to this reported IDS program; however, none has occurred during this program.

Examination of valve failures indicated the failures were probably due to two causes: inconsistency in the width of webs and inadequate thread count in some of the webs. A schematic of the valve is shown in figure 48.

Brailsford & Co. normally makes valves of Viton-impregnated Dacron but for the IDS application, because of the -40°F start requirement, they use silicone-reinforced fiberglass. The die employed to make the usual valves did not work well on silicone when punched by another concern. Brailsford & Co. now has the die and punches the valves in-house. The valves have improved but the die is still an inexpensive die. A better die is required, something which Brailsford & Co. apparently can't justify at this time. The Brailsford & Co. representative stated that the silicone material used previously was not as good as that presently used, a fact recently demonstrated under a NASA contract. Additionally, Brailsford & Co. altered the valve design from

0.007"-thick material to 0.010"-thick material and from ~40 threads per inch to ~60 threads per inch. Only valves which were punched relatively cleanly were used during this reported program, i.e., noticeably weak valves were not used. These changes apparently adequately improved valve life. Brailsford & Co. estimated a valve life expectancy of 5000 hours should be possible.

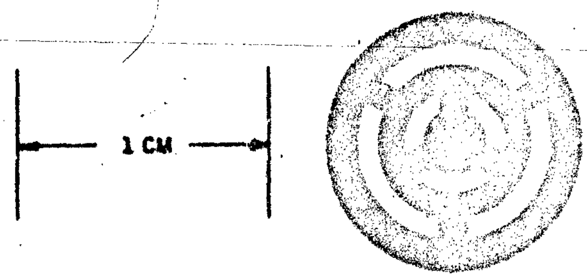



Figure 48. Brailsford Fabric-Reinforced Valve Showing the Six Webs

8. A Decrease in Flow with Time and Solutions -- A decrease in flow with time accompanies bearing, diaphragm, and valve degradation. Methods to solve these problems are discussed above. Other sources of decreasing flow with time exist.

The Brailsford version of the Scotch yoke (see figure 45) includes what is essentially a slot in the plastic element (connecting rod) which connects the two diaphragms of the pump. The outer races of the pair of bearings on the eccentric shaft attached to the motor roll along the two long sides of the slot in turn. To permit free rolling on one side, clearance must exist between the other side of the slot and the bearing race as indicated in exaggerated form by the solid circle. Such clearance is exchanged from side to side of the slot during operation of the pump. Associated with this exchange is impact not only of the bearings as discussed above, but also of the plastic by the bearing races. Such impacting indents the plastic as indicated in exaggerated form by the dashed circles to result in shorter pump strokes. Measurements of the indented regions correlate with the decrease in flow with time as observed for the Brailsford & Co. pump. The impact loading of eccentric and motor bearings due to the clearance may partially account for bearing failure due to impact peening or Brinelling of the races by the balls.

Another mechanism of flow decrease was discovered during studies of increasing pressure drop ($\Delta p$) across sensor modules with time by photographing cell parts. Particulate matter entering with the sampled air impacts against the outer wall of holes in cell baffles. This process builds up a dam to increase $\Delta p$ and decrease flow. Flow diverters at holes could lessen the problem, but the effect on cell performance would have to be studied. Figure 49 illustrates the mechanism just described.

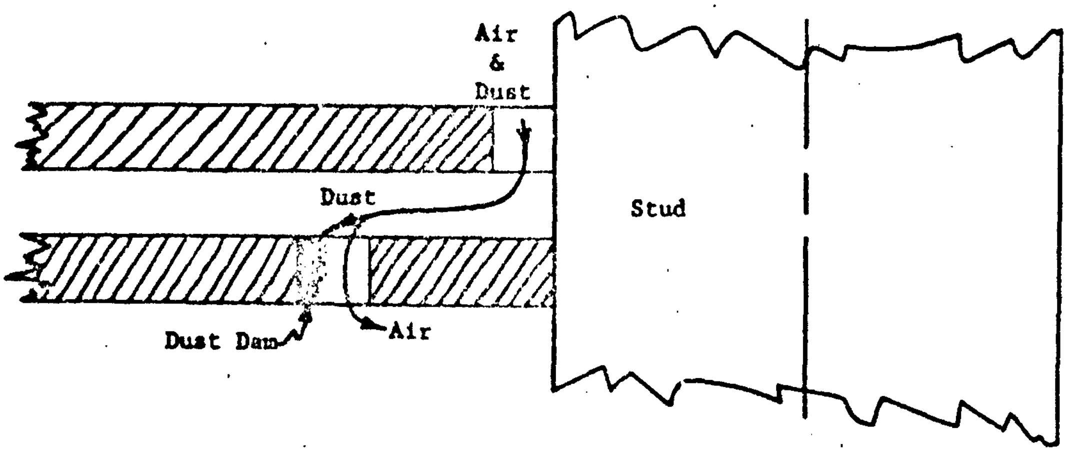



Figure 49. Illustration of Method of Blockage of Holes in Cell Baffles

Contaminants causing an increase of cell impedance with time were examined. Lint was very conspicuous on the source screen of the first cell in the flow stream in the unit under investigation. A special filter (figure 40) with a large screen area for the inlet of the sensor module was designed primarily as a grass and insect filter but also for lint removal. The filter screens have 0.010-inch diameter holes with 33 percent open area. The walls of these holes play a minor role as impact surfaces to stop dust. This inlet screen filter is not generally employed with a sensor module. In addition, the heater was redesigned to include a dust cup. A test in which the cell screens were replaced with screens having larger hole diameters (0.020 inch versus 0.010 inch) but smaller total open area (20 percent versus 33 percent) exhibited a faster increase of $\Delta p$ with time.

There exists an optimum particulate filtering situation. If too much particulate is filtered from air prior to its entering the sensor module, then particulate agents could not be detected by the sensor module. If too little is filtered, then the flow impedance of the cells would increase too rapidly. Filtering within the warm sensor module would still allow detection

of particulate or low vapor pressure agents. Honeywell believes the extent of particulate filtering is now close to optimum. If continuing tests suggest additional filtering is required, we suggest that the volume associated with the dust cup be used, as intended, for inclusion of impact surfaces or other filtering elements.

To offset residual decreases in flow, a motor pump speed control was developed and supplied with each of the three sensor modules delivered to Edgewood Arsenal. Flow control is not a very critical requirement for the IDS sensor module since the assembly incorporates an automatic flow compensation circuit.

9. Cold Start Test -- One concern with use of neoprene diaphragms was the possible problem of the motor pump not starting at low temperatures. Neoprene becomes quite stiff at low temperatures and the additional torque required might be too large. Tests were conducted at low temperature to determine if a problem existed. The sensor modules were soaked at low temperatures for a minimum of four hours. Both a Sperry motor and an E.A.D. motor were tested, both had neoprene diaphragms.

The Sperry motor started at both -40°F and -20°F. The E.A.D. motor failed to start within the temperature range of -40°F to 0°F. Tests were stopped at 0°F. The cognizant engineer from E.A.D. visited us at Honeywell August 8, 1973. Their motor design employs thermistors which can be changed to compensate for the thermal effects on motor element impedance. E.A.D. is confident they can correct this problem since they have for other applications. The problem arose from the fact that the motor for previous Edgewood Arsenal applications (D5-15-4602) has a cold temperature starting requirement of 0°F whereas that for this program has been -40°F with an anticipated change to a higher temperature.

10. Power Requirements -- Power measurements were made of the IDS module (ac power supply and Sperry motor) during the cold temperature test. These are noted below.

| Temp. | Power |
|---|---|
| -20°F | 54 watts (start-up) |
| -20°F | 48-49 watts (stabilized) |
| 0°F | 41-42 watts |
| 75°F | 29-30 watts |

Reducing flow was considered in order to reduce power and to extend motor pump life. Reducing the flow rate would conserve power in two ways. First by reducing the amount of air to be heated. As an example, * a flow reduction from 4 liters/minutes to 3 liters/minutes would result in a power reduction of 0.9 watt, considering only the power required to heat the air sample from 68°F to 140°F. From -40°F to +140°F, the power required to heat the

air flow would be 2.2 watts/liter/minute of flow. In addition, the power requirement of the pump would be reduced due to the smaller air flow.

---

*Let $\Delta T = 72°F = 40°C$.

The specific heat of air is $c_p = 7. \left[\frac{\text{cal}}{\text{mole--°C}}\right]$.

$$Q = m\, c_p\, \Delta T$$

$$P = a\, F c_p \Delta T, \quad a = \text{conversion factors}$$

$$P = \frac{10^3}{60}\left[\frac{\text{cm}^3}{\text{sec}}\right] \times \frac{1}{22.4 \times 10^3}\left[\frac{\text{mole}}{\text{cm}^3}\right] \times 7\left[\frac{\text{cal}}{\text{mole--°C}}\right] \times 4.18674\left[\frac{\text{joules}}{\text{cal}}\right]$$

$$\times\, 40\ [°C] = 0.87 \text{ watts for } 1\ \ell/\text{min of air}$$

$$P_4 = 4 \times 0.87 = 3.48 \text{ watts at } 4\ \ell/\text{min}$$

$$P_3 = 3 \times 0.87 = \underline{2.61} \text{ watts at } 3\ \ell/\text{min}$$

$$\Delta P = 0.87 \text{ watt or } 0.9 \text{ watt}/\ell/\text{min}$$

where

$Q$ = Heat, [joules]

$P$ = Power, [watts]

$F$ = Flow, [$\ell$/min]

D. Evaluation of Brushless DC Motors

Eight brushless dc motors were ordered for reliability studies; five were ordered from Western Air Devices, Inc. and three from Sperry Rand Corp., Marine Systems Division. Subsequently three additional motors were ordered from each supplier for use in tests and in three sensor modules for delivery to Edgewood Arsenal.

Prior to this IDS contract, each of the two companies mentioned above redesigned a 17 v dc brushless motor and consigned it to Honeywell for trials in sensor modules. The motors were redesigns of similar motors by the manu-

facturers, redesigned by the manufacturers to operate at 28-30 v dc with more torque to provide approximately five normal liters/minute of flow through the sensor module instead of the usual four.

After a series of tests, which revealed a number of small problems corrected by the manufacturers, one problem remained: the bearing on the output shaft failed within a thousand hours. Studies of the bearing problem indicated the failures were most likely due to impact loading of the output bearing due to excessive radial clearances in motor and pump eccentric bearings, outer races to bores (one such bore was hammered several thousandths of an inch out of round), inner races to shafts, spacers on shafts, and the intrinsic several thousandths clearance in the Scotch yoke as employed by Brailsford and Co. in their two-diaphragm pump which was used with the motors in test. This problem and the methods to solve it are presented above under Motor Pump Problems and Solutions.

Honeywell analyzed the motor and eccentric bearing problem but also sent to MPB (Miniature Precision Bearings) a number of failed bearings from motor pump assemblies made by Brailsford and one Brailsford motor intact which clearly had bad bearings. Brailsford & Co. sent to MPB a new, complete motor pump assembly. Prior to the IDS contract, Sperry had sent failed bearings from a prototype motor (part no. X003, serial no. 2) which Honeywell had tested in a MADS sensor module.

MPB personnel said (see appendix A) they agree with Honeywell's analysis--the Brailsford yoke design hammers the bearings to brinnell the races; the E-clip retaining the eccentric bearings on the Brailsford eccentric causes wear debris; the use of sealed bearings should be considered (although Brailsford found they cause too much drag torque); if temperatures exceed 150°F, Andok C grease should be ruled out (it's best up to 150°F MPB said) but Mobilgrease 28 is judged satisfactory (Honeywell specified Mobilgrease 28); MPB likes the magnesium rod design by Honeywell which employs doubly sealed bearings, 0.0001" to 0.0003" (P13) radial play bearings, and Mobilgrease 28; MPB recommended the use of their molded, glass-filled, Teflon ball retainer (MCK); for preloading they agreed with Honeywell's recommended 0.75 ± 0.25 pound-force and recommended a wave washer (Eastern Air Devices (EAD) employs this technique, Sperry has but doesn't for IDS) or a similar technique rather than a cap screw or equivalent which offers little control with frequent excessive preloading; MPB liked the idea suggested by Honeywell of a further eccentric refinement using duplex pairs of bearings for preloading.

One motor each by Brailsford, Eastern Air Devices, and Sperry was dissected to better determine its potential for a reliable unit for the IDS. The judgement was (and still is) that the best candidate is the EAD motor followed closely by the Sperry motor with the Brailsford motor trailing considerably. The judgement was based on the ability to control bearing alignment and to employ bearing preload. Fully sealed bearings were assumed. Sperry's was ranked second because of the use of a filament in a lamp which failed once in Honeywell tests.

and because Honeywell had not then (but has since) tested a Sperry motor with preloaded bearings. Brailsford's was ranked a far third because of the troublesome mechanically starting commutator, the use of through-bolts for alignment, and the use of plastic end plates on the motor into which the bearings are lightly pressed (possibly misaligned), and due to insufficient torque to employ sealed bearings.

1. Motors from Eastern Air Devices, Inc. -- Each of the motors in test from EAD has been performing satisfactorily. Table 2 above presents the results of these tests. As of August 20 a.m. the hours on #E-6, #E-7, #E-8, #E-9, and #E-10 (the last two were delivered to Edgewood Arsenal) were 5902, 5499, 1897, 1200 (est.), and 1200 (est.), respectively. Motors #E-8, #E-9, and #E-10 were supplied by EAD with four wires to permit speed adjustment over a wide range of speed with the use of the transistorized speed control described in a following subsection.

The EAD motor needs different temperature compensation thermistors to permit starting below 0°F. Future motors will incorporate this change. Starting at -20°F would require a simple change of thermistors. Starting at -40°F would require an additional circuit board in the motor. Alternatively, starting could be accomplished by providing an increasingly higher voltage to the oscillator with decreasing temperature. EAD and Honeywell are hopeful that the cold starting requirement temperature will be increased to -20°F or to 0°F as suggested feasible by characteristics of cw agents and recent conversations with military personnel.

2. Motors from Sperry Rand Corp. -- The first Sperry motor received during this program (X003, #3), had significant radial play at the output shaft; the other two which arrived later were similar in this respect. Measurements of the radial play of shafts of motors #4 and #5 showed it to be 0.0007" ± 0.001" for #4 and 0.0008" ± 0.0001" for #5 in each of two perpendicular directions. Honeywell and MPB considered this to be excessive. Motor #3 was in test so it was not measured at the time.

After a few days of testing, typical signs of the early stages of motor bearing failure became evident for motor #3. Such signs are decreasing speed and decreasing air flow with time, somewhat erratic motor speed when using an accurate motor speed measuring technique, and small spikes on the strip chart recording of the air flow. The test of motor #3 was terminated prematurely at 555 hours to ensure the possibility of a bearing-failure diagnosis by the bearing manufacturer, MPB. The radial shaft play was then measured for motor #3. Some difficulty was experienced in making the measurements due to fluctuations (perhaps due to brinelling of the races due to impact during the test), but the values seemed to be 0.0010" ± 0.0001" in one direction and 0.0015" ± 0.0001" in the perpendicular direction. Interestingly, the larger radial play was in the direction of bearing impact due to air pumping.

Testing of Sperry motor #4 continued, but it too commenced to show the same signs of the early stages of bearing failure. Motor #3 was returned to Sperry for tests and bearing analysis at MPB. The latter occurred when personnel from MPB, Sperry, and Honeywell met at Honeywell November 28, 1972, to discuss the problem associated with Sperry motor #3. The results are attached as appendix B. The basic problems were than an internal aluminum sleeve on the shaft next to the output bearing generated aluminum/alumina and steel wear debris directly into the bearing and the lack of bearing preloading. Loctite (appendix C) was recommended to solve the spacer motion problem. Loctiting bearing races to bores with a one pound dead weight during Loctite curing was the recommended bearing preload method.

Sperry motor #3, Sperry motor #4 (after 1005 hours of operation), and Sperry motor #5 (untested) were returned to Sperry for rework according to the Nov. 28 design meeting. As received after this rework, #3 had finger-noticeable lateral shaft play, so it was returned again to Sperry and as of Aug. 20 had not been returned to Honeywell. Sperry motors in test seem to continue to have some finger-noticeable lateral shaft play. Sperry was alerted to this, since a possibility exists of improper bearing preloading. No Sperry motors which had been improved according to the November 28th design meeting have failed in tests. If radial play still exists in the bearings, one conclusion is that overall improvements in the motor pump have sufficiently reduced bearing impact to provide long bearing life. Future Sperry motors like EAD motors will be delivered with four wires to permit more effective use of the transistorized speed control.

Table 2 above presents the results of these motor tests. As of Aug. 20 a.m. the hours on #4, #5, #6, and #8 (#8 was delivered to Edgewood Arsenal) were 3218, 3906, 162, and 1200 (est.), respectively.

A Sperry motor on a Brailsford & Co. pump with Honeywell improvements, test no. 5a, started at -40°F as reported elsewhere. Sperry is not willing to guarantee such a starting performance, however. Sperry and Honeywell are hopeful that the cold starting requirement temperature will be increased to -20°F or to 0°F as discussed elsewhere.

3. Brailsford Motors -- Brailsford motors have been generally quite unreliable with a present Mean Time Between Failures (MTBF) of a few hundred hours. Still, some, as though of a second group, have been running for thousands of hours. Failures have been basically but not exclusively of two types: failures to start due to contaminated brushes/pins and pin hang up and bearing failures. There have also been electronic failures, probably transistor failures. Brailsford employs a mechanical commutator for startup only. The brushes become contaminated to the extent that the motor can't be started; cleaning them with Freon 113 permits startup. Also the centrifugally switched pins stick in the running position.

Brailsford examined the startup problem. They found that some stampings of parts of the starter mechanism were rough and burred on the outer surfaces where physical contact is made with the inner surface of the surrounding Delrin plastic. Brailsford found that on a random basis, the rough surface

of the starter mechanism would grab the plastic and jam. By removing the roughnesses, jamming ceased to occur. Subsequently Brailsford made a new die for the stampings which solved this particular problem. Still existing is startup failure due to contaminants, discussed below.

Tests at Brailsford have not confirmed Honeywell's experience with the contaminant startup problem or the more recent MTBF of a few hundred hours. Originally, prior to this program, 30 motor pump assemblies (model no. TD-4X2F) were purchased. The motor bearings were originally lubricated with an oil (vs. a grease) to facilitate startup at low temperatures. The MTBF was then a few tens of hours which was confirmed by Brailsford tests. The oil employed was a silicone oil (Versilube, F50). Silicone oils are now rejected.

Since our tests agreed when silicone oil was employed, Honeywell and Brailsford have been attempting to determine the difference in the tests at Honeywell and at Brailsford to account for our present, different test results. At Honeywell the motor pump assemblies are run at ~140°F under load (4 to 5 n ℓ/min, 30 to 40 inches of water pressure drop) with the output shaft vertical down). The tests at Brailsford are similar but the shaft is horizontal. Motor clamping is the same. Honeywell therefore suspected a contact angle problem in the motor bearings.

Brailsford recently examined its records to find that of the 30 motor/pump assemblies purchased as lubricated with silicone oil, 21 were returned for overhaul. Of these; 13 were overhauled with motor bearings using a different oil (LO-2, a "diester" oil) and eight were overhauled with motor bearings using grease (LG-39, Andok C by Humble Oil).

The current tests at Brailsford are with motors using bearings lubricated with LG-39 grease. The difference in our test results therefore may be that the 13 units we've used with LO-2 have bearing failures at the output end of the motor shaft (a fact) as well as but less frequently at the commutator end of the shaft (a fact). The latter would cause wear debris to contaminate the brushes to prevent start-up.

For seven Brailsford motor pumps that failed, motor failures (sometimes due to several problems) are presented in table IV. This table does not contain failures due to contaminated brushes which were cleaned nor does it contain failures of Brailsford eccentric bearings.

**Table IV Failures Modes of Seven Brailsford & Co. Motors**

| Failure Mode | Lubricant | |
|---|---|---|
| | LO-2 | LG-39 |
| Electronics Failure (Not commutator) | 3 | 3 |
| Motor Bearing Failure | 3 | 0 |

The data in table IV is sparse but it suggests that the difference in test results at Honeywell and at Brailsford has been due to bearing failures of the thirteen overhauled units lubricated with LO-2 oil as compared to Brailsford test units lubricated with LG-39 grease. The failure rate analysis is made more complicated by the camouflaging effect of electronic failures.

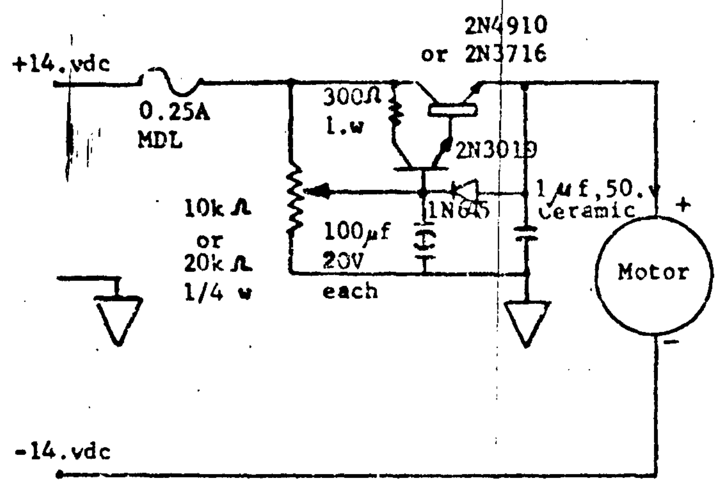
Brailsford & Co. overhauled at its expense two motor-pumps shipped to them by Honeywell. They are now in test as test nos. 7 and 8. One (XTD-4X2 in test no. 7) was modified by Brailsford to give higher flow through the IDS sensor module. Both have revised motor and eccentric bearings, revised starters, and revised electronics; however, Brailsford retained the Scotch yoke which has been so troublesome. Each has displayed marks on its recording of sensor signals. Each has exhibited starting problems. Brailsford unit XTD-4X2 in test no. 7a appeared and sounded to be experiencing a serious motor bearing failure. The test was terminated at 783 hours on April 13, 1973 and returned to Brailsford for examination. As reported to Brailsford at the time, each unit sent to Brailsford for overhaul had had starting problems as well as other problems. Brailsford reported it has one motor in starting tests which has undergone $10^6$ startups without failure. They have observed only a few starting failures with other units. In one case, resin from soldering operations got between the starter pins and brushes of the centrifugally switched starting commutator. The other failures were due to unspecified contaminants.

The Brailsford motor pump number XTD-4X2 in test 7a which was returned to Brailsford at 783 hours because of a starting problem and presumed bearing noise did not have a bearing failure per se as thought, but the plastic Scotch yoke aged, closed, and clamped the outer race of the eccentric bearing to cause the yoke to hammer against its housing. Brailsford repaired this. The repaired unit (test number 7b) also failed to start several times. Slapping the bottom of the ac power supply on the sensor module would cause the motor to start. However, at 2054 hours the motor would not start at all--it had zero torque at zero rpm. Yet when started manually it ran well. The unit was returned to Brailsford for examination. The total time on the unit (tests 7a and 7b) was 2837 as of test termination July 25, 1973. Thus the two Brailsford units in test have each presented problems: TD-4X2 in test number 8a failed to start at 232 hours and XTD-4X2 failed to start several times and had a Scotch yoke problem.

The advantages of the Brailsford motor pump--if problems could be eliminated--would be that it is a single complete package from a single supplier and that it is inexpensive as compared to the special units assembled at Honeywell. Honeywell is continuing to encourage Brailsford & Co. to develop its motor pump to satisfy IDS application requirements.

E. Speed Control

A new, transistorized speed control was designed as shown below (figure 50). For the last three motors of the order of five, EAD brought out four wires, two to connect to a constant 28-30 v dc supply for the motor's internal




Note: The two 100μf capacitors can be removed if the fuse is removed.

Figure 50. Design of Transistorized Motor Speed Control

oscillator (which requires at least 20 v dc, more nearly 23-24 v dc to run) and two for speed control. EAD maintains that the speed of the motor can then be completely controlled using a voltage as low as ? v dc if desired. Honeywell experinece supports this claim--its speed controls very well.

Sperry believes their motor (which has an internal capacitor between its leads) can be used directly on the transistorized speed control. Honeywell experinece supports this claim--its speed controls very well unless the voltage is lowered unreasonably far. If 26 v dc becomes the required coltage, they could supply motors designed for the new average design voltage rather than the present 28 ± 2 v dc. However, future motors from Sperry will also have four wires brought out for total speed control.

The speed control can be used with Brailsford & Co. motors but the motor speed should be kept safely above the speed at which the mechanical starting commutator engages. This speed is approximately 2000-2400 rpm.

The transistorized speed control was incorporated into three IDS units delivered to Edgewood Arsenal. The physical location of the trim pot adjustment is on the right side of the sensor module when facing it along with the flow compensation and alarm level adjustments. A more detailed discussion of these adjustments is outlined in section III. The electronics for this modification are located behind the front panel and attached to the top surface of the sensor module.

### F. Evaluation of Other Motor Pump Combinations

While working to improve the life expectancy of the present motor pump assembly, Honeywell Inc. pursued alternate solutions as well. One, presented above, was the use of another manufacturer's motor on a Brailsford & Co. pump with Honeywell improvements. A second was the replacement of the Brailsford & Co. TD-4X2H motor pump assembly with a suitably performing assembly of similar dimensions and power consumption. The third was the use of a heavy-duty motor pump assembly to be operated on 115 v ac or 230 v ac 60 Hz power. This assembly was to be housed in the ac power supply module to be called an ac power module, the dc brushless motor in the sensor module would be disconnected electrically. Sufficient electrical pins exist that connector modifications would not have been required. Flow switching was to be performed by check valves. A general design was developed for this third approach, but a detailed design awaited the arrival of the heavy-duty motor pump assembly. This arrival was inordinately delayed and did not include a motor. Only recently was the motor pump assembly put into tests which have not been impressive. The ac power supply/pump module was not completed.

Some thirty letters (appendix D) were mailed to pump manufacturers in August 1972. None was sent to Mace Corporation, Gast Manufacturing Corporation, or Brailsford & Co. since Honeywell had been in contact with these companies earlier. None of the responses to the letters was favorable.

Figure 51 compares three motor pump assemblies under consideration.

1. Mace Corporation -- The design of the replacement for the Brailsford & Co. motor pump assembly progressed at Mace Corporation. Honeywell mailed to Mace a Brailsford TD-4X2H motor pump assembly and gave them the requirements. The president of Mace Corporation was confident that a reliable substitute could be designed but did not complete the design. Due to other more urgent business activities, he dropped the effort but suggested he might continue upon request in the future.

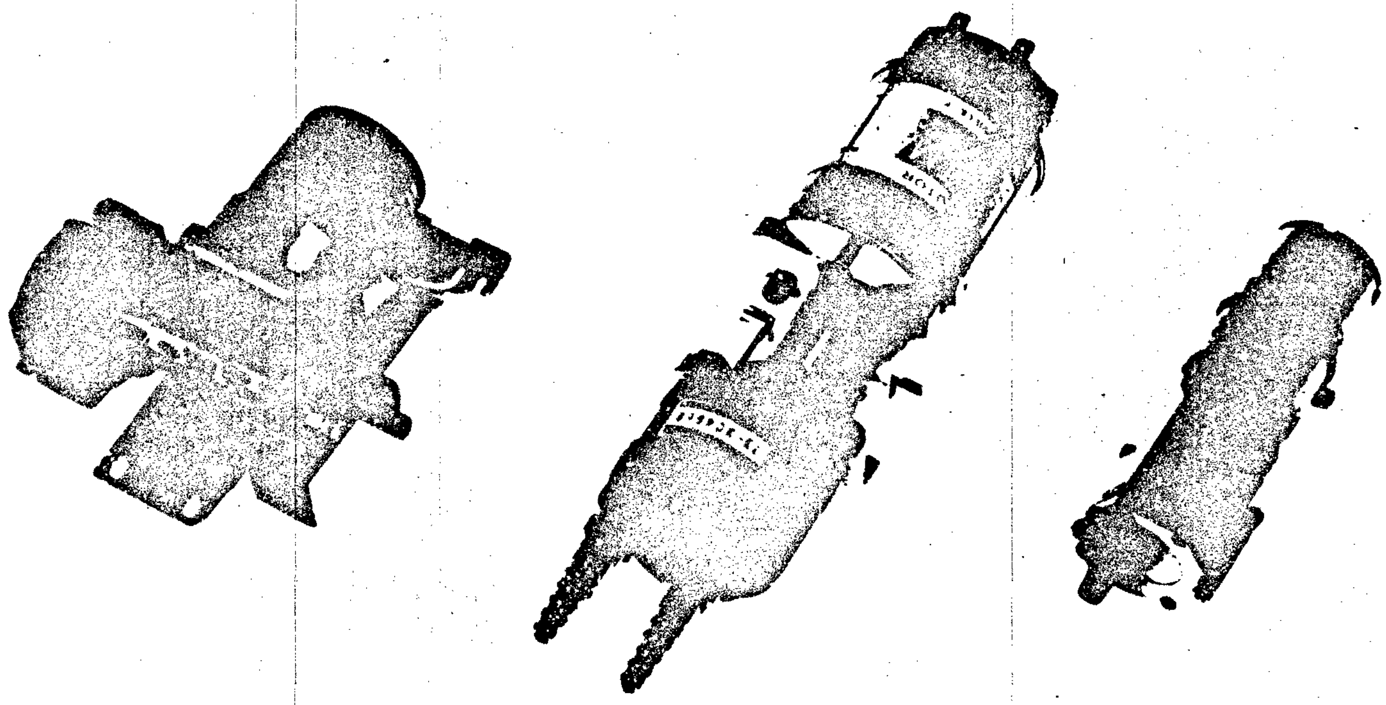
2. RPC Corporation -- Recently received on consignment from RPC Corporation a miniature motor vane pump, model no. 9004,03, serial no. A. See figure 51 and appendix E. This unit was designed to fit into the sensor module as a replacement for the Brailsford & Co. two-diaphragm pump. In fact, the RPC motor vane pump combination is much smaller. The assembly supplied was tested and found to be capable of pumping five normal liters of air per minute with a pressure drop of 40 inches of water. Reliable, long-life, efficient motors are available but were not available within a short time for this assembly--thus the assembly employs a motor which requires 22 v dc and 460 milliamperes. This current in addition to the heater current is too large for an IDS sensor module to deliver. The pump is expected by RPC to be very reliable and long-lived since pump elements have shown negligible wear after 2000 hours. DC brush motors with lifetimes exceeding 4000 hours in this application are reasonable according to RPC. The anticipated price for the motor vane pump was estimated to be $125 in lots of 50 to 100.

3. Gast Manufacturing Corporation and The Pittman Corporation -- Negotiations with Gast Manufacturing Corporation were initially favorable. Gast sent a knowledgable sales engineer to visit to determine first-hand the nature of the problems of the heavy-duty motor pump assembly. As a result of this meeting, Gast agreed to construct and consign to Honeywell a heavy-duty, integral motor pump assembly which would fit into the ac power supply module.

The unit delivered did not contain a motor. Gast suggested contacting The Pittman Corporation about a motor. Pittman altered three motors with slightly different characteristics to be used with the Gast vane pump. After fabricating a mounting fixture and obtaining a shaft coupler, the unit shown in figure 51 was placed in room temperature tests with a proper load. Each of the three Pittman motors appeared adequate. The test is continuing with 255 hours as of August 20, a.m. Occasionally squeals, chirps, and irregular flow seem to be associated with the assembly. One source of noise was shown to be internal to the Pittman motor. As of August 20 we're not very optimistic about the outcome of the tests.

## VIII. IMPROVEMENT OF THE SURFACE CONTAMINATION MONITOR

Within the MADS program the surface contamination monitor (SCM), in its qualified configuration, did not meet the intended design objectives. The surface temperature probe as shown in figure 52 had two deficiencies: its



Brailsford Two Diaphragm Pump with Eastern Air Devices DC Brushless Motor

Gast Vane Pump with Pittman DC Brush Motor

RPC Vane Pump with an ITT Brush Motor

Figure 51. Three Motor/Pump Assemblies under consideration for the Ionization Detector

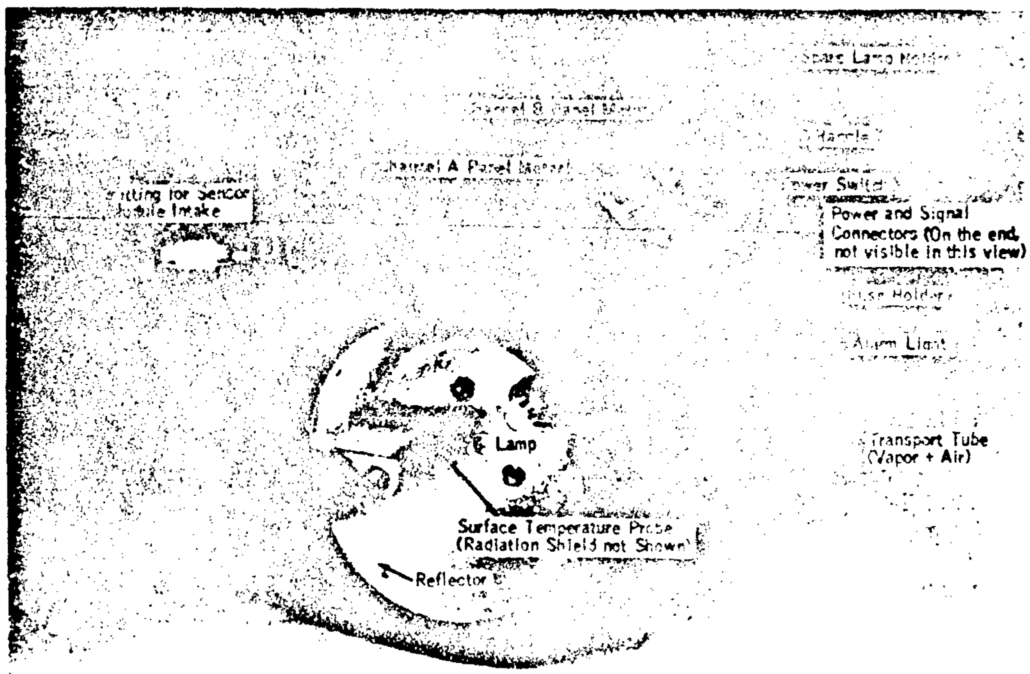



Figure 52. Surface Contamination Monitor without Radiation Shield for Surface Temperature Probe

thermal mass was too large and it was excessively sensitive to the radiant flux under the reflector. In tests, the sensitivity to radiant flux was partially eliminated by employing a polished radiation shield as shown in figure 53. The probe's large thermal mass, evident in figure 54, was attacked during the MADS program by designing a new probe shown in figure 55 with a similar geometry but by employing a bead thermistor in a small thermally insulated copper tip instead of the much more massive wire-wound resistance element of the original probe.

Tests of the improved probe with a radiation shield showed it to control surface temperature very well. Changing to the improved probe involved more than a simple substitution of the probes in that the two required circuits are different--the original probe has a positive temperature coefficient of resistance whereas the new probe has a negative coefficient.

During the present IDS program three SCM's were retrofitted with a radiation shield and a further improved surface temperature probe with the necessary circuit changes and circuit improvements. The redesigned surface temperature probe was given a designation of A-T: TP#, where "#" designates the serail number. The original probe manufactured by Minco Products, Inc. (their S51) is a fine probe but does not meet the IDS application requirements. All of the changes incorporated into the SCM are reflected on the updated prints.

The Honeywell probe was further improved in the reported IDS program by selection of better materials of construction. The copper tip was made more durable with respect to wear by drilling the cavity for the thermistor less deep.

The SCM has never been environmentally tested, in part because the SCM has always been the lowest priority component of the system. Recent discussions with the U.S. Air Force indicated that aircraft components will be provided to Edgewood Arsenal for use in environmental tests. It is quite likely that the transport tube will require an internal, full-length heater to prevent condensation of vapor on its internal surfaces.

Data from tests conducted with the original and the improved surface temperature probe with and without the radiation shield are presented in the following pages for comparison.

A. Surface Temperature Control

The Minco S51 surface temperature probe, a tip-sensitive probe, is made for bearing (and other) temperature measurements where such bearings are buried deep in machinery. The probe, tests show, is not strictly applicable to the environment of the SCM ( nor did the manufacturer intend it to be); yet, with a radiation shield, the Minco S51 probe performs reasonably well.

In the SCM environment, the Minco S51 probe's performance is degraded due to its design (figure 54) and large mass. For example, the copper tip extends as an approximately 0.015-inch-thick thin-walled copper tube, enclosing a tape-

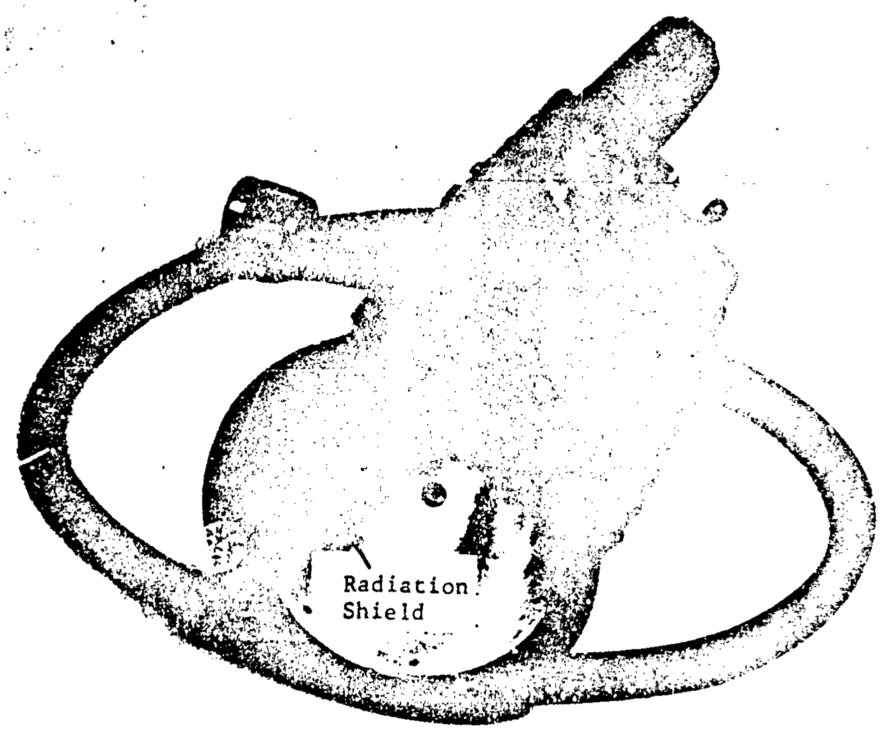



Figure 53. Surface Contamination Monitor with Radiation Shield for Surface Temperature Probe

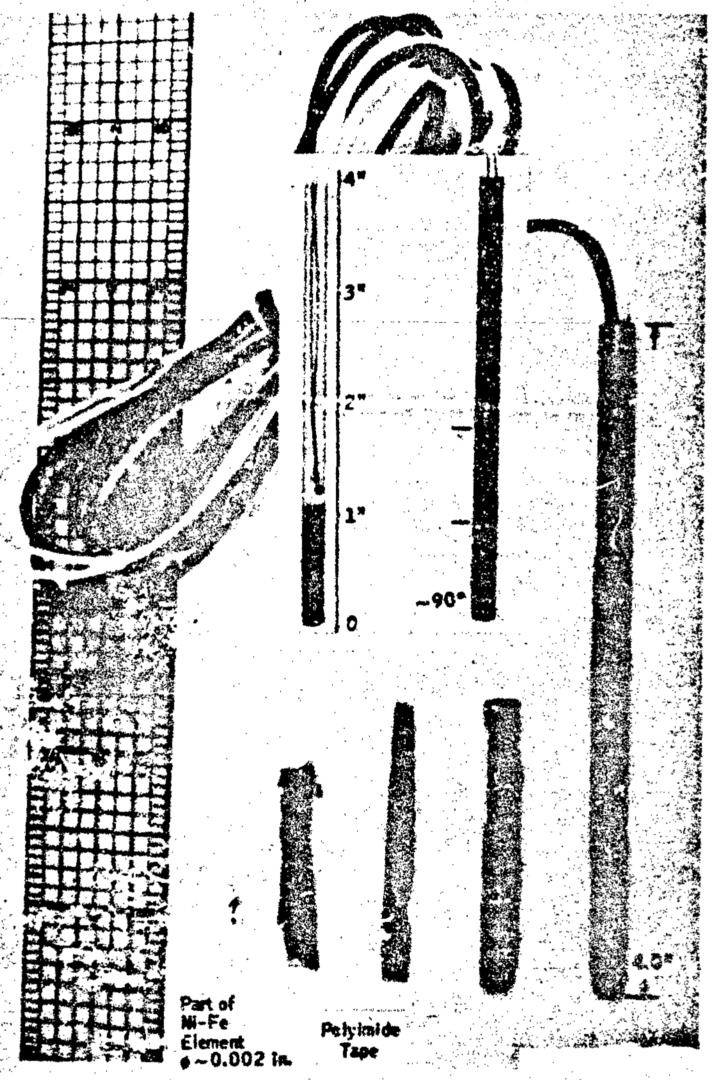



Figure 54. Photograph of a slit Minco S51 Probe and an X-ray of another one showing major components: the thin-wall stainless (~ 0.011 in.) steel tubing, the copper tip with its 2-in.-long thin-wall (~ 0.015 in.) extension extending into the stainless-steel tubing, the layer between the resistance wire element and the copper of what appears to be polyimide tape (Kapton?) with an adhesive to bond the close-wound Ni-Fe resistance wire element, a fragment of the ~ 0.002-in.-diameter Ni-Fe resistance wire element (arrow), a 2-in. length of strain relief material (probably an epoxy) filling the tube, and the 2 lead wires (the plastic insert to prevent cutting of the wire insulation by the stainless steel tubing is missing in the photo). The exact design of the Minco S51 probe is Minco Proprietary.

covered 676-ohm (at 25°C) Ni-Fe resistance element about two inches into the stainless-steel (Type 304) shaft, itself with a wall thickness of about 0.011 inch. This results in the probe being highly radiant-flux sensitive and air-temperature sensitive, causing considerable droop. The Minco S51 tip-sensitive probe is, however, the best commercially available probe discovered for the SCM application.

The new probe (designated Honeywell A-T:TP3, see figure 55) consists of a seamless, stainless-steel (Type 321), polished tube with a wall thickness of about 0.006 inch. A small copper button mounted in Teflon® and inserted into the tube forms the tip of the probe. A thermistor (Victory Engineering Company No. GS51A132 or equivalent) is suitably imbedded in the copper tip. The dimensions of this probe are such that it can be substituted for the Minco S51 probe by making the appropriate electronic changes in the bridge circuit in particular.

Table 5 and figure 56 present numerous test results under similar conditions for the Minco S51 and the Honeywell A-T:TP3 surface temperature probes with and without a radiation shield. Clearly, on the basis of these tests, the best unit is the Honeywell A-T:TP3 with the radiation shield. However, as shown in figure 56, the Minco S51 with a radiation shield performs reasonably well for usually encountered temperatures at which the CW agents of concern are likely to exist on surfaces. For example, the CW agents of concern will not remain long on a surface which is much above room temperature, in particular at temperatures approaching 60°C.

Other tests with an SCM as controlled by a Honeywell A-T:TP3 surface temperature probe showed the following: (1) good temperature control on a large shiny aluminum plate (3 feet x 4 feet x 0.063 inch) as shown in figure 57; (2) no damage to flat black paint (considered the worst-case paint) on a standard 5 x 5 x 1/8-inch thick test plate; (3) no damage to a tan-colored paper Crown Multifold Towel No. 041; (4) no damage to a gray Dacron® smock; and (5) no damage to a white Dacron® smock. Each paper and fabric tested was tested over the flat-black painted plate mentioned above. The manufacturer of the smocks said the Dacron® smock would be more prone to scorching than the Nylon® smock, so presumably a Nylon® smock if similarly tested would be undamaged, too.

B. Time Response

The response time of a surface temperature probe is a function of several items: the effective power into the object being irradiated (a function of reflectances, power losses, pulsing circuit operation, and lamp power--hence the lamp, supply voltage, and supply current); the mass, density, thermal conductivity, and specific heat of the object; the required temperature change for a response; and the extent to which the object is heat-sinked (by convection and conduction primarily). Thermodynamically speaking, the use of a finite power source cannot sensibly increase the temperature of a true heat reservoir; the use of 250-watt (maximum) power source in the SCM to significantly increase the temperature of several square inches chosen at random of an aircraft would

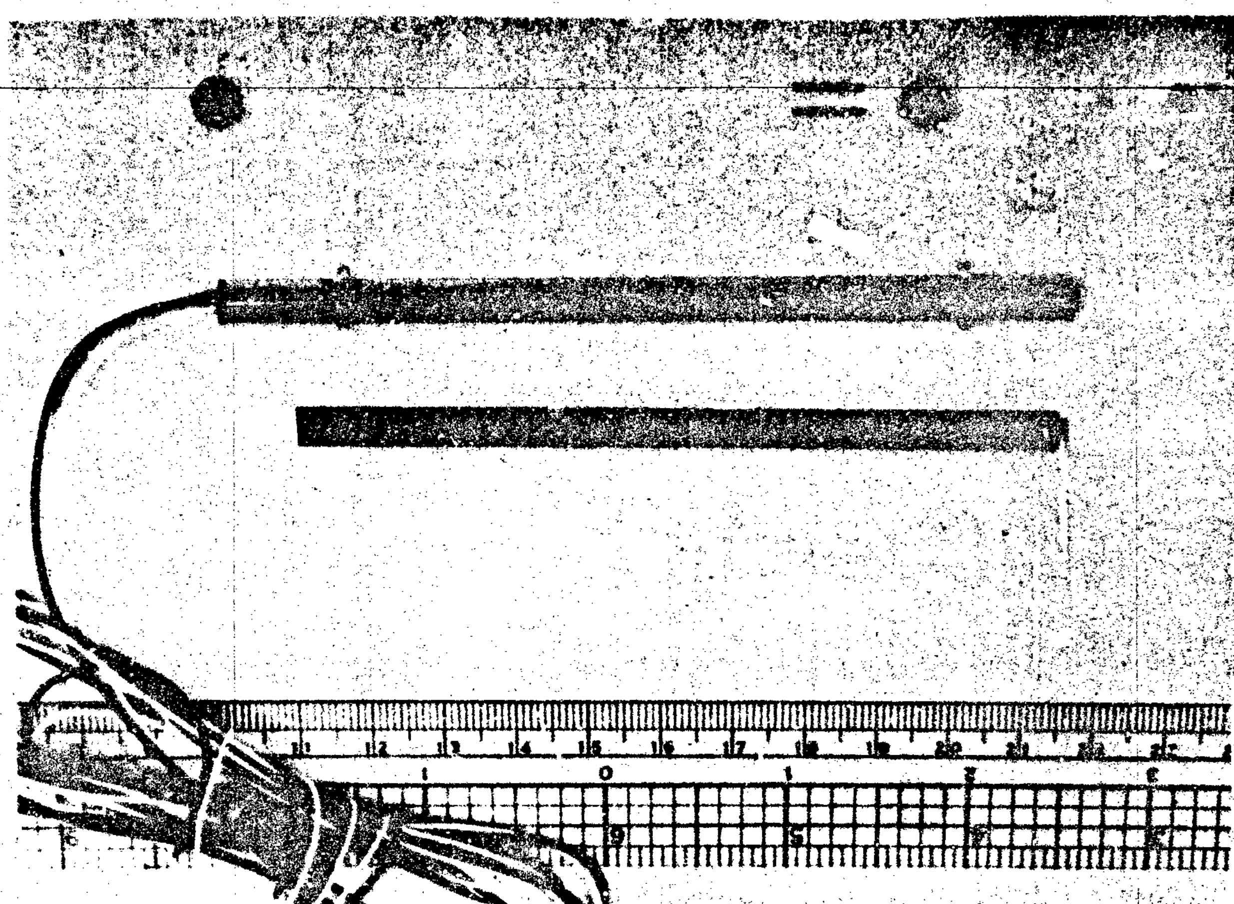


Figure 55. Photograph and X-ray of Honeywell A-T:TP3 Surface Temperature Probe Showing Components: copper button, thermistor, Teflon insulator, tie pins, thin-wall stainless-steel tubing, Teflon strain relief, and the two lead wires

**TABLE V** Characteristics of Surface Temperature Probes with and without Radiation Shields

| Run No. | Probe Tested | Conditions P | Conditions R | Conditions D | Plate Temperature (°C) $T_{start}$ | $T_{1st\ lamp\ off}$ | $T_{15\ minutes}$ | Important Times $t_1$, $t^*$ (minutes) | | $t_1 + t^*$ (minutes) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Radiation Shields** | | | | | |
| 4 | A-T:TP3 | x | x | x? | -43.9 | 49.7 | 51.4 | 8.0 | 0 | 8.0 |
| 3 | A-T:TP3 | x | x | x? | - 1.7 | 50.6 | 52.8 | 4.1 | 0 | 4.1 |
| 2 | A-T:TP3 | x | x | x? | 25.8 | 52.2 | 54.4 | 2.0 | 0 | 2.0 |
| 1 | A-T:TP3 | x | x | x? | ≥55.6 | Lamp never on 55.6 | 55.6 | 0 | 0 | 0 |
| 12 | S51 | --- | x | x | -40.6 | 46.9 | 50.0 | 9.8 | 0.6 | 10.4 |
| 11 | S51 | --- | x | x | - 0.6 | 54.4 | 60.6 | 4.8 | 1.7 | 6.5 |
| 10 | S51 | --- | x | x | 26.9 | 52.2 | 63.3 | 2.2 | 3.3 | 5.5 |
| 9b | S51 | --- | x | x | 52.2 | 67.2 | 75.6 | 1.1 | 3.0 | 4.1 |
| 9a | S51 | --- | x | x | 59.4 | 70.3 | 77.2 | 0.75 | 2.6 | 3.4 |
| | | | | | **No Radiation Shields** | | | | | |
| 8 | A-T:TP3 | x | --- | x? | -41.7 | 40.8 | 44.2 | 7.0 | 0.3 | 7.3 |
| 7 | A-T:TP3 | x | --- | x? | - 3.3 | 40.3 | 49.4 | 3.2 | 2.2 | 5.4 |
| 6 | A-T:TP3 | x | --- | x? | 27.2 | ~45 | 52.2 | ~1.3 | ~1.6 | ~2.9 |
| 5 | A-T:TP3 | x | --- | x? | ≥55.6 | Lamp never on 55.6 | 55.6 | 0 | 0 | 0 |
| 16 | S51 | --- | --- | x | -40.6 | -16.7 | 18.9 | 1.3 | 10.6 | 11.9 |
| 15 | S51 | --- | --- | x | - 1.1 | 8.2 | 37.2 | 0.63 | 9.1 | 9.7 |
| 14 | S51 | --- | --- | x | 25.8 | 31.9 | 50.6 | 0.39 | 8.5 | 8.9 |
| 13 | S51 | --- | --- | x | 58.9 | 61.1 | 70.6 | 0.079 | 7.0 | 7.1 |

$t_1 = t_{T_{1st\ lamp\ off}}$, (minutes)

$t^* = t_{(T_{15\ minutes} - 5°F)} - t_1$, (minutes), $\geq 0$

$= t_{(T_{15\ minutes} - 2.78°C)} - t_1$, (minutes), $\geq 0$

x denotes conditions of tests.

x? denotes D was used but it was not obviously active. In recent IDS tests the pulsing circuit D (for dynamic element) was found to be unnecessary and was disconnected.

--- denotes absence of these conditions in tests.

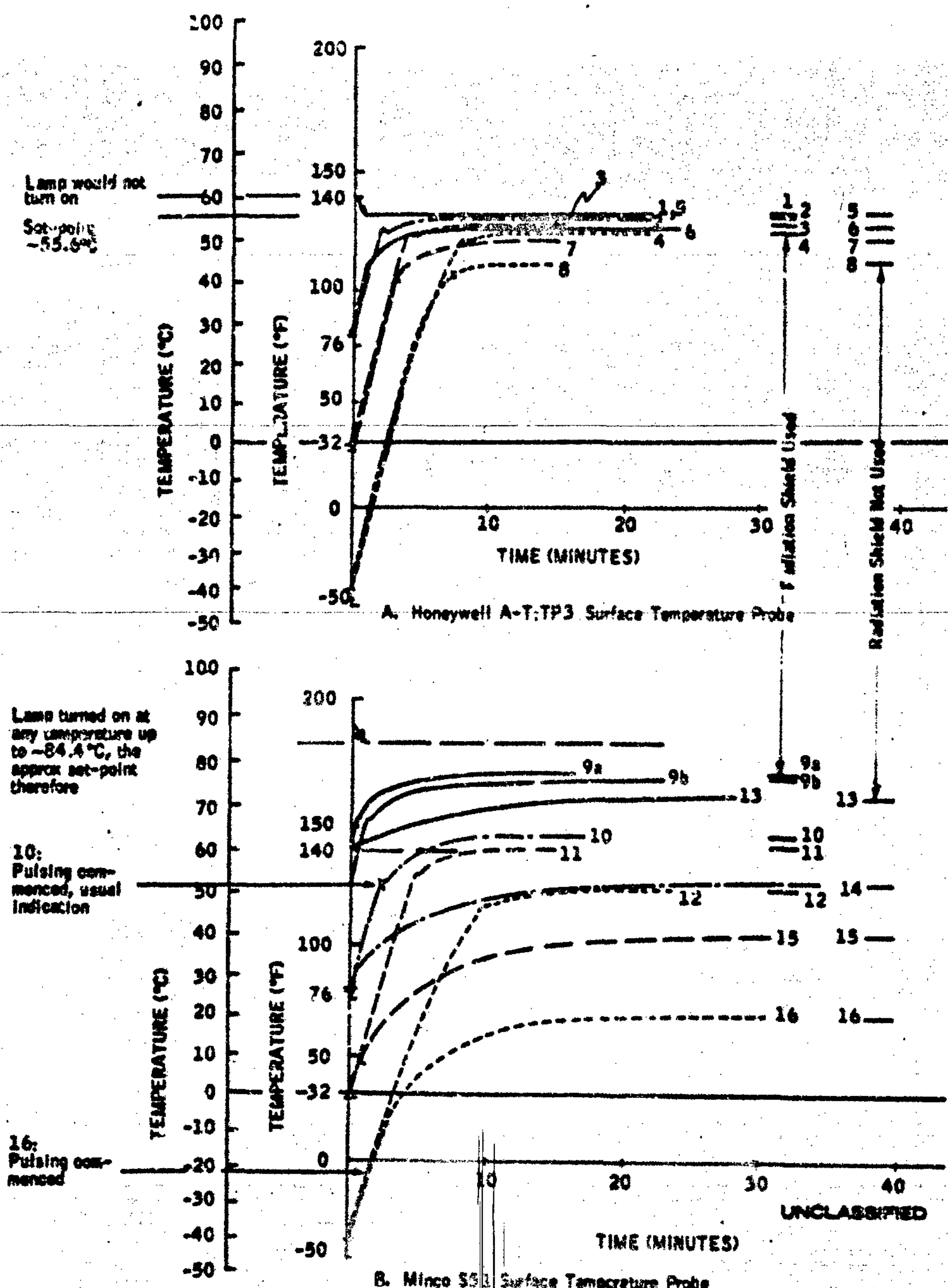



Figure 56. Temperature of Insulation-backed 5 x 5 x 1/8-in. Aluminum Test Plate Versus Time and Ambient Temperature as Controlled by Two Different Surface Temperature Probes With and Without Radiation Shields for Vertical Orientation of, and No Air Flow Through, the IDS Surface Contamination Module

undoubtedly yield regions where only small temperature increases would result. Still, areas such as those of the skin of the aircraft which are somewhat distant from large masses of the aircraft structure could be used as discussed below. Other candidate areas are inspection plates.

The usual laboratory test plates have been 5 x 5 x 1/32-inch thick to 1/8-inch thick, although much thicker plates have been used. The time to reach the control temperature increases as the thickness of the plate increases. Figure 57 shows surface temperature (as indicated by a thermocouple on the back of the plate) versus time when an SCM, as controlled by a Honeywell A-T:TP3 surface temperature probe with a radiation shield, was used to irradiate a large shiny aluminum plate (3 feet x 4 feet x 0.063 inch) initially at room temperature. This test plate was placed lengthwise on a smaller table (24 x 32 inches) with a single-layer cotton shop towel at each corner and the usual 5 x 5 x 1/4-inch foam insulation at the center bottom (under the thermocouple).

When the system reached thermal equilibrium, the temperature of the plate was warm to the touch only within four or five inches of the rim of the SCM. On this basis one can assume that the area of a wing or any other portion of the aircraft with a skin thickness of ~0.060 inch which is located away from rivets and large masses by about a one-foot radius, could serve adequately for contamination/confirmation monitoring. More extensive tests using actual aircraft should be run to validate this assumption. Compare the response time characteristics shown in figure 57 with those of figure 56.

The response of a surface temperature probe is not limited to the probe's characteristics, per se, but it is also affected by the probe/surface material interface and the diffusivity of the material whose temperature is being measured.

In another experiment, the two candidate probes, Minco S51 and Honeywell A-T:TP3, which were initially at room temperature, were quickly inserted into an oven at 60°C onto materials of different thermal conductivities. The output signal from each probe was recorded and the time constant in each case was determined. A plot of the data is presented as figure 58. The Honeywell A-T:TP3 probe yielded results superior to those of the Minco S51 probe.

## IX. DEGRADATION OF THE TRITIUM RADIOACTIVE SOURCE WITH TIME

A tritium ($H^3$) source is used in each IDS cell. This source is formed by evaporting a titanium film onto a stainless steel substrate. Tritium is then reacted with the titanium to form the tritide (hydride), i.e., $TiH^3_2$. A number of possible modes of degradation of such sources exists. Additional studies are required to rank the modes, but the change in IDS sources to operate on the specific ionization current-specific source activity plateau may have by-passed the need for such a ranking. Time will tell.

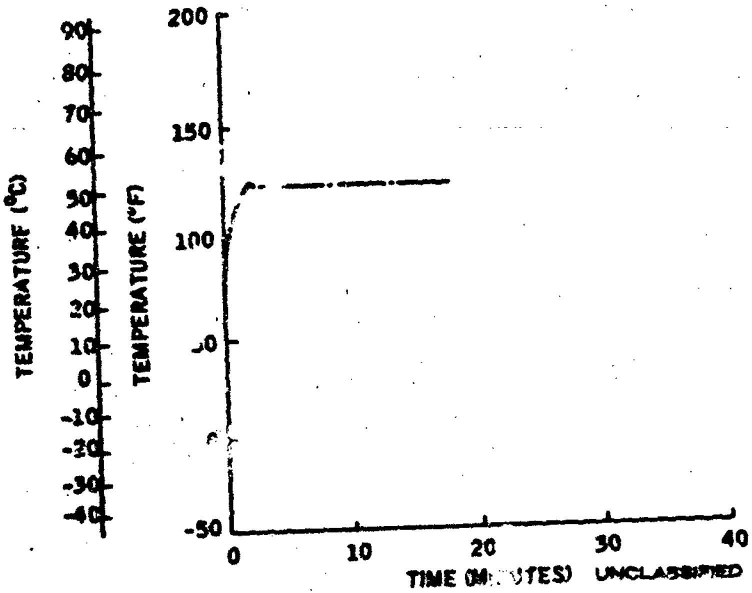



Figure 57. Surface Temperature versus Time for a 3-feet by 4-feet by 0.063-inch Horizontal Plate of Shiny Aluminum Initially at Room Temperature as Irradiated by an SCM with a Honeywell A-T:TP3 Surface Temperature Probe Plus Radiation Shield. (The plate was supported by a 24 x 32-inch table and insulated at the corners and center from the table.)

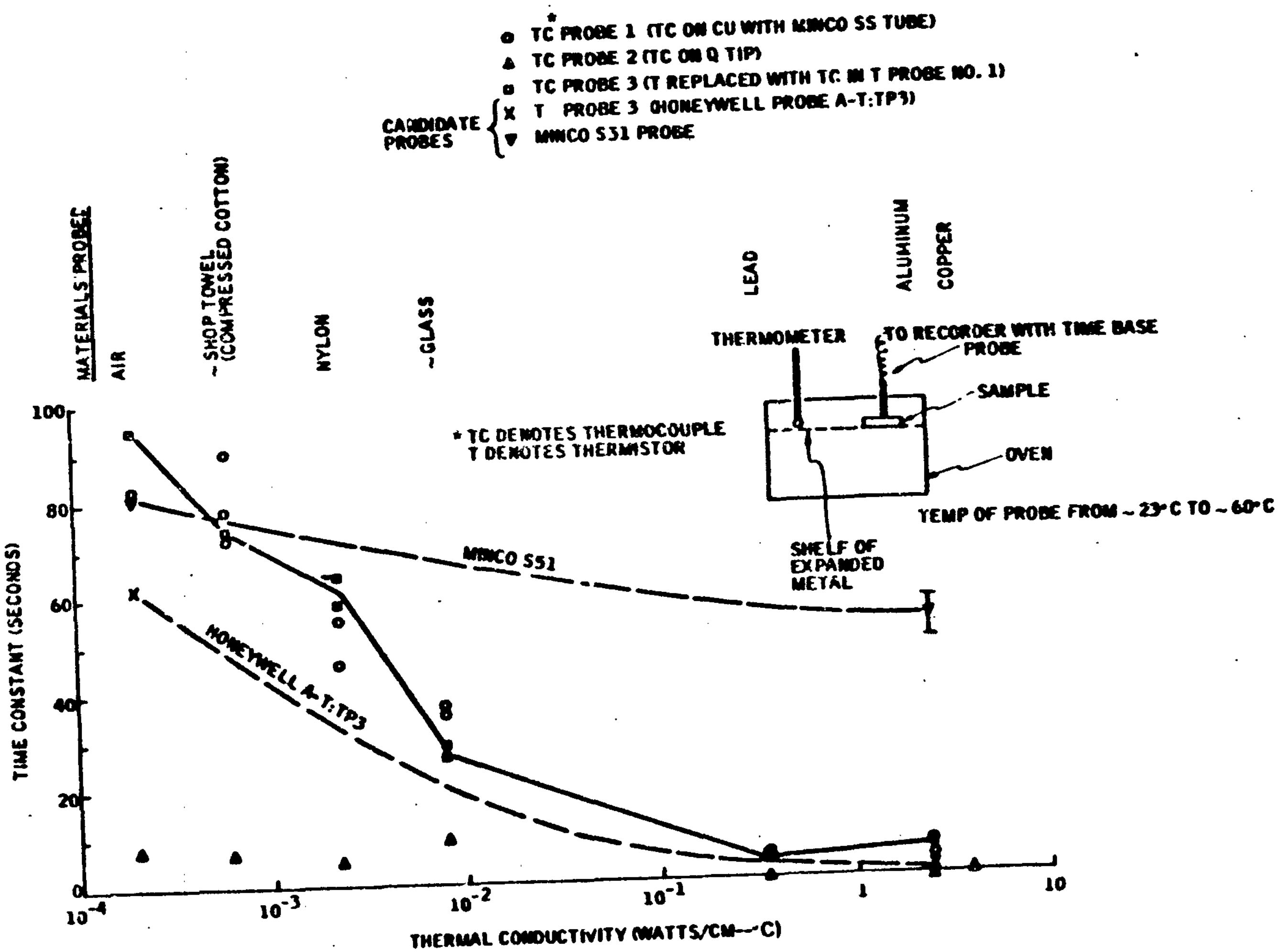



Figure 58. Time Constants of Several Surface Temperature Probes as a Function of the Thermal Conductivity of the Surface Material

Some of the modes of source degradation are radioactive decay, tritium emanation (ref. 1), an initial decrease (with a plausible explanation), surface contaminating deposits (ref. 2), tritium exchange with hydrogen of water vapor in air (a debated phenomenon), and increased self-attenuation by change of average source density due to debris filling interstices and pores which resulted from the growth process of the vacuum-deposited titanium film. These and other points are discussed below.

A. Operation on the Specific Current-Specific Activity Plateau

In terms of IDS performance, a reduction of the observable degradation of tritium sources as they are presently fabricated was attempted by employing higher intensity sources. The MADS units employed a source intensity of 250 mCi, a square 1/2" x 1/2" of material with a specific activity of 1 Ci/in.$^2$. By employing a source with the same area but with a specific activity of 4 Ci/in.$^2$ to yield a 1 Ci source, reduction of degradation was thought possible by operating on the specific current-specific activity plateau as shown in figure 11 supplied by U.S. Radium Corporation but modified for use herein. Note in figure 11 that for a given source area, the slope is greater at a specific activity of 1 Ci/in.$^2$ than at 4 Ci/in.$^2$ on the plateau. Thus a change in the effective source activity should result in a smaller change in response for an IDS cell with a source made of 4 Ci/in.$^2$ material than of 1 Ci/in.$^2$ material. As discussed in section II, the higher intensity sources are being used in the IDS system. Time will tell whether the anticipated result of slower effective source degradation has been met.

B. Sources with Discoloration

Sources have been monitored during this IDS program as reported below. A new phenomenon was observed--some sources turned blue with an associated decrease in ionization current of a factor of two. The phenomenon is not yet understood. The color resembles that due to Tyndall light scattering such as would occur if large particles such as islands of $TiH_2^3$ formed on the foil. Such island growth with a resultant Tyndall blue light scattering is frequently observed with vacuum-deposited thin films. The blue light scattering is a phenomenon like that associated with Rayleigh scattering which causes blue skies. The IDS sources operate at approximately 140°F (60°C) with a flow of room air over them of four to five normal liters per minute. Vapors of malathion and DDVP pesticide (room temperature vapor pressures) were used for a few minutes as often as daily to check instrument responses. The positions of the cells with blue sources do not correlate with cell position (up to three cells per instrument, hence up to three sources per instrument) or other factors. Not all sources turned blue. A charcoal filter ahead of a source did not always prevent the blue color from developing. Cleaning the sources did not restore the ionization current nor did it totally eliminate the blue coloration. The blue coloration had a superimposed pattern of the outlet holes in the cell manifold, the air exhaust ports for the ionization chamber.

U.S. Radium has observed a similar phenomenon. Certain sources turn blue at the time of production when heated to tritiate them. They have found no correlation between this blue phenomenon and temperature, orientation, or any other factor considered. The blue does not occur until tritiation commences. The substrate is vacuum metallized in one building and stored in an inert gas. Substrates are cut to the required dimensions and placed in a quartz pot which is then evacuated. Tritium gas is introduced (in a different building), the temperature is increased, tritiation commences at ~200°C - 300°C, and then some sources turn blue. Blue sources are not shipped to customers. The sources as received by Honeywell were not blue but the usual gray. The primary difference between the two "types" of blue is that the U.S. Radium employee contacted did not believe that the source activity was lower than required by specifications whereas at Honeywell the activity was off by a factor of two. A possible explanation is given by figure 11 in that the minimum/maximum ratio is approximately one-half. Alternatively, if islands were to form after a couple of weeks or more, self-attenuation would decrease the effective activity of the source.

### C. Purely Radioactive Decay

Purely radioactive decay reduces the activity of tritium to 94.5%, 89.3%, 84.4%, 75.3%, and 50% in one, two, three, five, and 12.26 years, respectively, as shown below. Such a decay would seem to be compatible with the life of IDS cells themselves, their lives being limited to a few years by contaminants normally present in the atmosphere at which time cleaning or replacement of the tritium source and cell would be required.

Shoemake, Fenimore and Zlatkis (ref. 3) considered eight isotopes ($H^3$, $Tc^{99}$, $Ra^{226}$, $Am^{241}$, $Sr^{90}$, $Ni^{63}$, $Kr^{85}$, and $Pm^{147}$) for sources in electron capture cells in gas chromatographs. Since the ionizing chamber in an IDS cell is similar to that in an electron capture cell, their findings may be applicable. Tritium, radium-226 and americium-241 were found to perform similarly (except titanium tritide should not be used at temperatures above 225°C). They favored americium-241 over radium-226 because of the former's lower energy gammas emitted along with the alpha's. Americium-241 is also inexpensive. Furthermore it has a half-life many times that of tritium, specifically 457 years as compared to 12.26 years. A cell was fabricated and tested with americium-241 sources as outlined in section I.

If the activity of a source decays purely by radioactive decay, its activity follows an exponential decay given by

$$n = n_o e^{-\lambda t} \tag{6}$$

where

$n$ = the activity at time $t = t$, [mCi, millicuries]
$n_o$ = the activity at time $t = t_o = 0$, [mCi]
$\lambda$ = the decay constant as empirically determined, $\left[\text{years}^{-1}\right]$
$t$ = time, [years]
$e$ = Napierian Base $\cong 2.718281828$, [--]

(Note that "n" as used in equation 6 designates a source activity, i.e., disintegrations per second since a curie is $3.7 \times 10^{+10}$ disintegrations per second, whereas "n" often designates the number of undisintegrated nucleii in the source at time t. In such a case the activity is given by $n\lambda$ where $\lambda$ is the decay constant as employed in equation 6. But since $\lambda$ is a constant, $n\lambda$ can be replaced by a new symbol "n" with the units of $n\lambda$ to designate source activity as is done herein.)

The half-life, T [years], is related to $\lambda$ when $n = n_o/2$ by

$$\frac{n_o}{2} = n_o e^{-\lambda T} \tag{7}$$

or

$$e^{\lambda T} = 2 \tag{8}$$

Thus,

$$\lambda T = \ln 2 \cong 0.69315 \tag{9}$$

A plot of the measured activity over time to indicate decay of the activity of a source would best be on semi-log graph paper to determine its relationship to radioactive decay as given from equations 6 and 9 by

$$\begin{aligned} \log n &= -(\lambda \log e)\, t + \log n_o, \quad (\log e \cong 0.43429448) \\ &\cong -\left(\frac{0.69315}{T} \times 0.43429\right) t + \log n_o \\ &\cong -\frac{0.30103}{T}\, t + \log n_o \end{aligned} \tag{10}$$

For tritium, from reference 4, the half-life is

$$T = 12.26, \quad [\text{years}] \tag{11}$$

Hence

$$\log n\,[\text{mCi}] \cong -2.4554 \times 10^{-2}\, t\,[\text{yrs}] + \log n_o\,[\text{mCi}] \tag{12}$$

or

$$\log n\,[\text{mCi}] \cong -2.0461 \times 10^{-3}\, t\,[\text{mos}] + \log n_o\,[\text{mCi}] \tag{13}$$

or

$$\log \frac{n}{n_o} \cong -2.0461 \times 10^{-3}\, t\,[\text{mos}] \tag{14}$$

Figures 59 and 60 present equation 12 and figure 11 presents equation 14. To use figures 10 and 11, simply plot the initial source activity, $n_o$ (which is the activity at any desired time but at a time called $t = 0$) at $t = 0$ and one-half that activity ($n_o/2$) as the ordinate with the half-life of the isotope as the abscissa. Figures 60 and 61 do this for several $n_o$'s of tritium, $_1H^3$.

D. Tritium Emanation with Temperature

Kahn and Goldberg (reference 1) found tritium foils operated at 210°C in gas chromatographs emanate tritium. The emanation depends upon foil temperature, the activity of the foil, and the nature of the carrier gas. They found that the logarithm of the tritium emanation $\mu$Ci/hour plots linearly (with a negative slope) against reciprocal absolute temperature in accordance with the Arrhenius temperature dependence common to chemical reaction rates.

The worst case they considered was for a 250 mCi source in a Wilken's detector for a gas chromatograph. The emanation rate (Em) was found to be

$$\log Em = -7.069\left(\frac{10^3}{T\ °K}\right) + 16.602,\ \left[\mu Ci/hr\right] \tag{15}$$

Since the IDS sensor module operates at 60°C,

$$T = 60°C + 273.15°K = 333.15,\quad [°K] \tag{16}$$

and

$$\frac{10^3}{T[°K]} \cong 3 \tag{17}$$

for which equation 15 becomes

$$\log Em = -21.207 + 16.602 = -4.605 = 0.395\text{-}5 \tag{18}$$

Hence

$$\frac{dn}{dt} = Em = 2.48 \times 10^{-5},\ 60°C,\ \left[\mu Ci/hr\right] \tag{19}$$

How does this compare with purely radioactive decay? From equation 6, upon differentiating with respect to time, we have

$$\frac{dn}{dt} = -\lambda n_o e^{-\lambda t} = -\lambda n \tag{20}$$

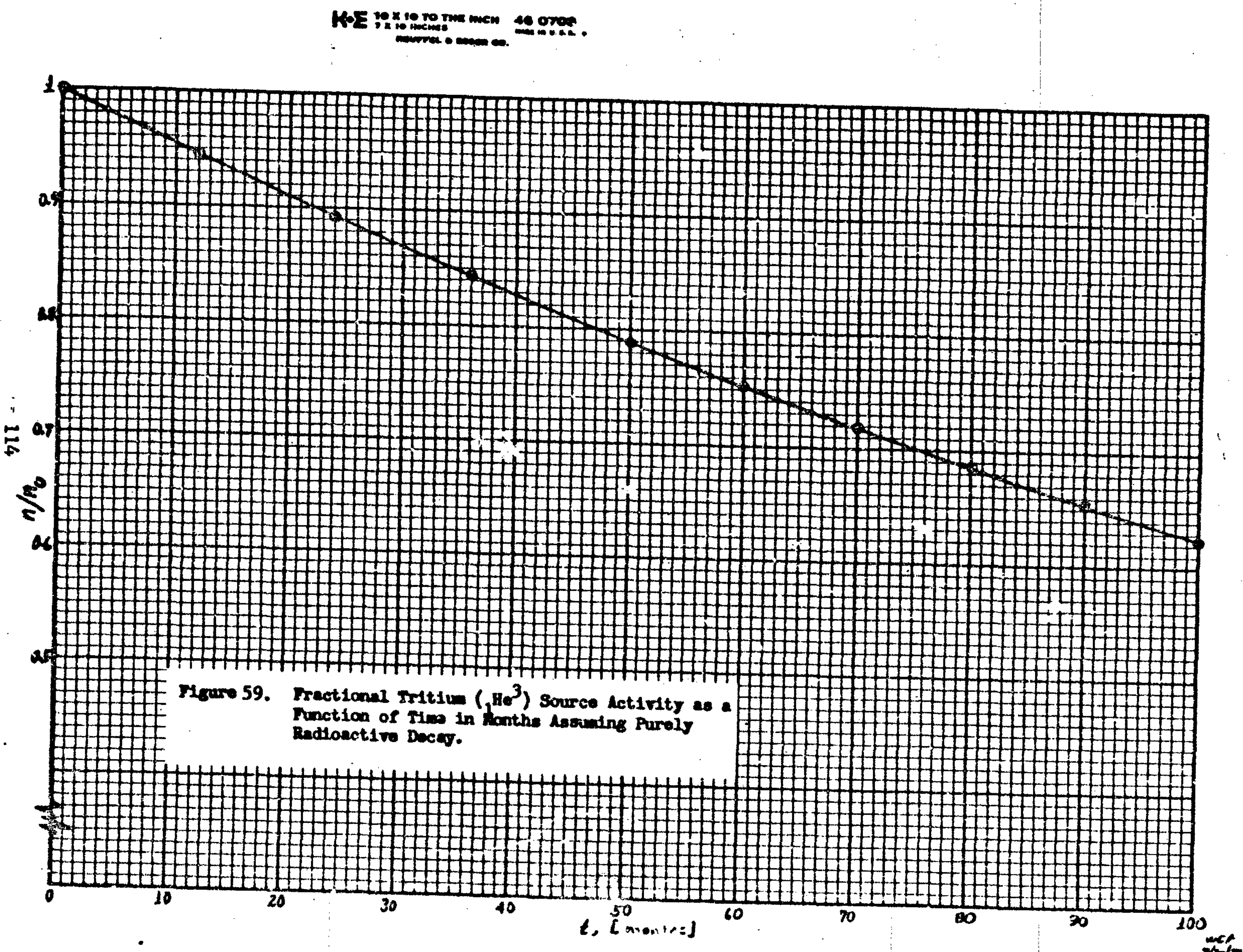



Figure 59. Fractional Tritium ($_1He^3$) Source Activity as a Function of Time in Months Assuming Purely Radioactive Decay.

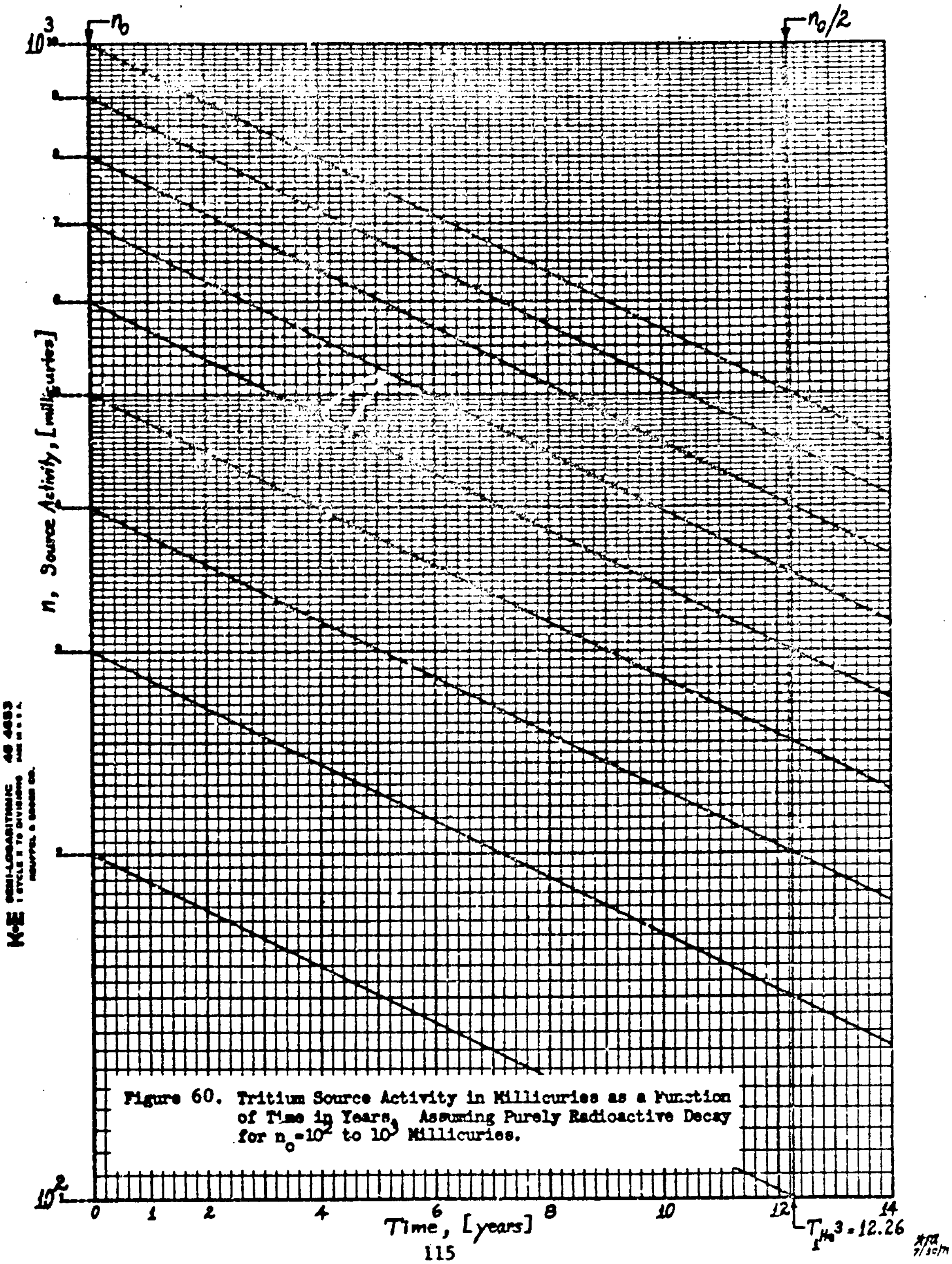



Figure 60. Tritium Source Activity in Millicuries as a Function of Time in Years, Assuming Purely Radioactive Decay for $n_0=10^2$ to $10^3$ Millicuries.

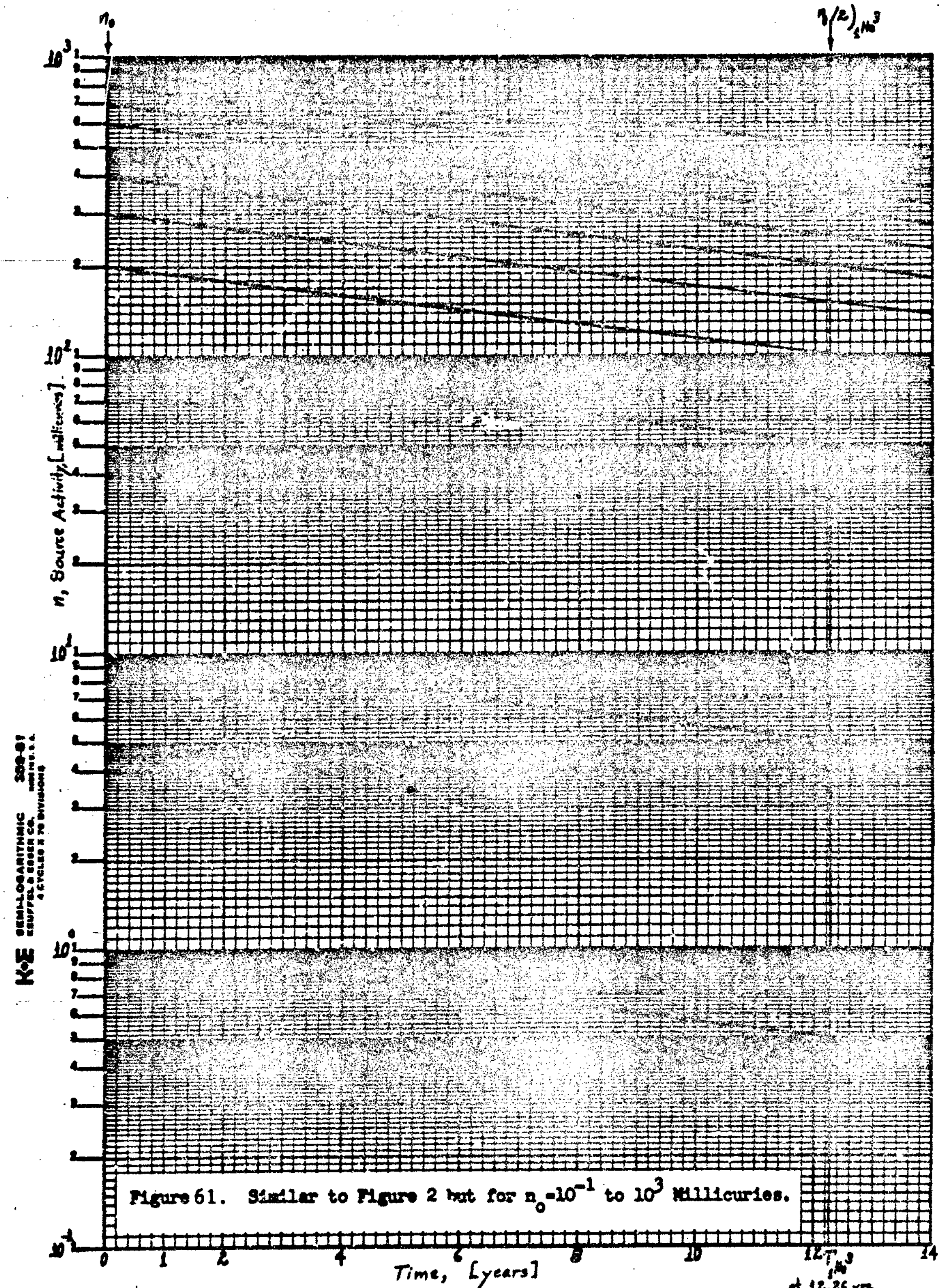



Figure 61. Similar to Figure 2 but for $n_o = 10^{-1}$ to $10^3$ Millicuries.

For this calculation, let's use the units employed by Kahn and Goldberg, i.e., $\mu$Ci and hours. Thus consider

$$n \cong n_o \cong 0.25 \times 10^6, \left[\mu Ci\right] \tag{21}$$

and from equations 9 and 11

$$\lambda = \frac{\ln 2}{T} \cong \frac{0.69315}{12.26 \left[years\right] \times 8{,}765 \left[hours/year\right]} \tag{22}$$

$$\cong 6.44 \times 10^{-6}, \left[hour^{-1}\right]$$

Combining equations 20, 22, and 21 gives

$$\frac{dn}{dt} = -1.61, \left[\mu Ci/hr\right] \tag{23}$$

Comparing equations 23 and 19 indicates that for the IDS sensor module operating at 60°C, the Kahn-Goldberg effect can be ignored as it is negligible as compared to purely radioactive decay.

E. Initial Fall-off

U.S. Radium observes an approximately 10 percent drop in activity of a foil during the first two or three weeks after fabrication and then not another change of 10 percent for a year or so. This initial (first two weeks or so) drop-off occurs even though the foil is stored in a dessicated container. The foil itself is usually copper or stainless steel and serves as a substrate for the tritiated titanium. (Materials other than titanium can be tritiated.) This initial fall-off is worse for copper than for stainless steel substrate foils. Such a fall-off phenomenon has not yet been satisfactorily explained, but it is thought to be due to outgassing of unreacted tritium from pores and other small volumes in the tritiated, vacuum deposited titanium film.

F. Source Contamination

Contaminating deposits can form on a tritium foil and thereby reduce its effective activity. Pesticides have been shown to cause such a reduction even at temperatures of 160-210°C (reference 2). Some chemical agents are similar to pesticides so they may affect IDS cells in a similar manner at the IDS internal temperature of 60°C. The lower temperature in the IDS cells would tend to worsen such a process whereas the continuous air flow and usually trace agent concentrations would tend to be offsetting factors. Laboratory experience with pesticides suggests these deposits are not a problem with the IDS sensor modules. However, such contaminated foils can be restored to nearly original activity (sometimes higher) by solvent and abrasive cleaning processes (ref. 2). Special care but simple care must be taken in either case but especially with the use of abrasives to avoid contamination of the premises. In the case of the IDS tritium sources discussed above which turned blue and which had their ionization current reduced by two, the solvent cleaning method (ref. 2) did not restore the ionization current, in fact the ionization current was barely increased (see table VI).

Another mode of source degradation by "contamination" is thought to be tritium exchange with hydrogen of water in the atmosphere. There have been two diametrically opposed schools of thought on this phenomenon -- one has said it occurs, the other has said it does not.

Due to the mechanism of growth of the vacuum-deposited titanium film, pores and interstices presumably develop in the film. These pores and interstices may fill with miscellaneous contaminants which could increase the average density of the film. The soft beta emission would thereby be attenuated to a contaminated film. Such an enhanced attenuation phenomenon is believed to have occurred in extraordinarily severe salt fog tests with IDS units during the MADS program, although corrosion of the stainless steel substrate and the titanium tritide are also possible explanations.

### G. Source Monitoring

An air ionization chamber (figure 62) was constructed to monitor source activity. The chamber has the dimensions of the one employed by U.S. Radium in order to duplicate their measurement techniques, yet to be demonstrated. Whether duplication can be achieved or not is not too important; relative measurements with the same measurement facility will be satisfactory.

Some sources have been measured. The results follow in Table 6 with remarks.

## X. ROUGH HANDLING STUDY

A study was made to determine the packaging design changes which could be anticipated for the IDS system to meet the environmental and rough handling tests specified in MIL-STD-810B, dated 15 June 1967. The results of this study have been included in a seperate report #F2081-IR-1. Briefly, this report outlines the general considerations in designing for dynamic environments and recommended packaging practices for rough handling. Projected designs for the IDS modules are discussed. A candidate design of the sensor module features shock isolation of the inner case using a resilient foam cushion between it and the outer case. Design of the dc power supply could be similar utilizing the same principles for shock resistance. A ruggedized design of the surface contamination monitor would have cylindrical inner and outer cases with intervening resilient structure.

## XI. ELECTROMAGNETIC INTERFERENCE TEST RESULTS

The IDS system was tested per MIL-STD-826A. After the modifications, which are listed below for the respective modules, the system passed all the requirements of MIL-STD-826A.

Appendix F includes the circuit schematic diagrams for the sensor, ac power, command post and surface contamination modules. All circuit modifications made to correct EMI deficiencies which are listed below are shown on the respective schematic.

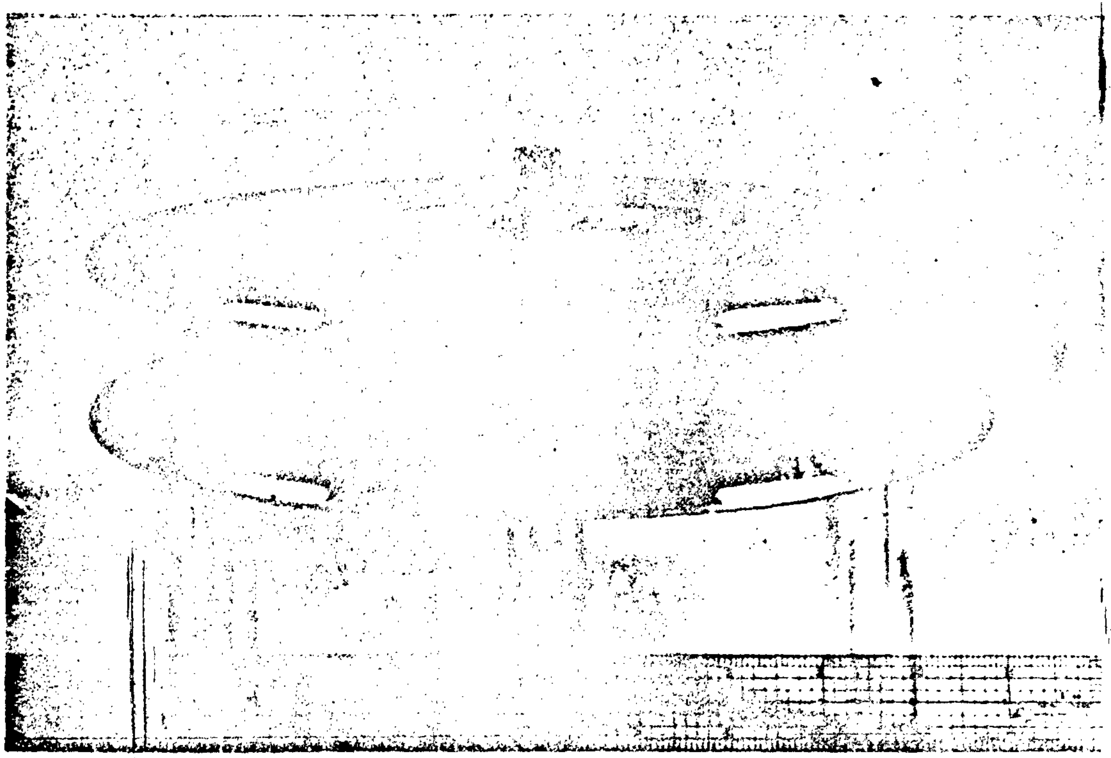


Figure 62. Source Monitoring Fixture

Table VI Tritium Foil Output

| Source Intensity | Age | Output @ 5 KV (Amps $HO^{7}=$ ) | Remarks |
|---|---|---|---|
| 1 Ci | New | 6.1 | |
| 1 Ci | New | 6.22 | |
| 1 Ci | New | 6.22 | |
| 1 Ci | New | 6.25 | |
| 250 mCi | Used, over two years old. | 3.35 | From a cell which had been in a MADS sensor module for several years; cleaning and retesting made little difference. |
| 250 mCi | Used, over two years old | 3.35 | From a cell which had been in a MADS sensor module for several years. |
| 1 Ci | Used 5-6 mos. in an IDS sensor | 3.05 | Source was blue as described in the text; cleaning in a KOH solution changed the output to 3.15. IDS life tests. |
| 1 Ci | Used 5-6 mos. in an IDS sensor | 5.6 | After cleaning in a KOH solution output was 5.85. IDS life tests. |
| 1 Ci | Used 5-6 mos. in an IDS sensor | 3.7 | Source blue; being used in IDS life tests. |
| 1 Ci | Used 5-6 mos. in an IDS sensor | 3.45 | Source blue; being used in IDS life tests. |
| 1 Ci | Used 5-6 mos. in an IDS sensor | 3.15 | Source blue; being used in IDS life tests. |

Table VI Tritium Foil Output (Continued)

| Source Intensity | Age | Output @ 5 KV (Amps $NO^7$ =) | Remarks |
|---|---|---|---|
| 250 mCi | Used over two years old | 2.75 | Being used in IDS life tests. |
| 1 Ci | Used 5-6 mos. in an IDS sensor | 5.65 | Being used in IDS life tests. |
| 1 Ci | Used 5-6 mos. in an IDS sensor | 3.3 | Source blue; being used in IDS life tests. |
| 250 mCi | Used over several years old | 3.7 | Being used in IDS life tests. |

A. Sensor Module EMI Modifications

- Circuit Board A1 (Front Panel)

  Added C6 through C11, L1 and L2

- Circuit Board A3 (Sensor Circuit)

  Added C9 through C14

- Circuit Board A6 (Amp and Alarm Circuit)

  Added C5 and C6.

- Motor/Motor Speed Control Circuit

  Added L1 and L2.

- Sensor Module Chassis

  Added a connection from inner case to signal ground. Added insulating sleeve on the inside of the air intake. (This insulator ensures electrical insulation between the outer case and the circuits of the sensor module.

B. A.C. Power Module EMI Modifications

- Added C9 through C14 and L1.

C. Surface Contamination Module EMI Modifications

- Added C5 through C8 and L1.

D. Command Post Monitor Module EMI Modifications

- Added C7 through C17.

## XII. AGENT SENSITIVITY AND FIELD INTERFERENCE TESTS

Both the C.W. agent sensitivity and field interference tests were conducted at Edgewood Arsenal by Edgewood personnel. The sensitivity tests were conducted by utilizing standard laboratory agent generators which exposed the detectors to known agent concentrations. The three modified IDS detectors were tested with the C.W. agents 'VX','GB' and 'GA' over a wide range of concentrations. Field interference tests were conducted on a test field at Edgewood with the detectors exposed to a number of common field interferences. The field tests were qualitative with no attempt to control concentrations.

The three detectors were tested with agent 'VX' to known concentrations ranging from 0.18 to 8.0 $\mu g/l$. The response in volts of the detectors versus concentration in $\mu g/l$ is displayed in graphs 63, 64 and 65. For comparison, an unmodified unit, number #19, was also tested with agent 'VX' at similar concentrations. These results are shown in graph 66. The response of both channels A and B is shown in these graphs, although channel B is used for the detection of high concentrations of agent 'GA'.

The filtered air or clean air base line for both channels is also displayed. The response of a unit is the total voltage span from the filtered air base line to the response curve at a specific concentration. The alarm level is shown as a dashed line. Changing the alarm level setting moves both the filtered air base line and the response curve either up or down with respect to the alarm level without effecting the total response.

As noted from graph 65, the alarm setting for sensor module #15 was marginal at lower concentrations of agent 'VX' The alarm level has since been adjusted to shift both the response curve and the filtered air base line up approximately 0.5 volts with respect to the alarm.

The three modified detectors were exposed to the c.w. agent 'GB' at concentrations ranging from .05 to 2.0 $\mu g/l$. These results are displayed in graphs 67, 68 and 69. Within the range of concentrations tested, the detectors have not shown any saturation effects to this agent. However both the respons curves for channels A and B are shown. The response data for unit #19 is also shown in graph 70.

Graphs 71, 72 and 73 show the response of the detectors to agent 'GA' for concentrations from 0.1 to 150 $\mu g/l$. As noted from the data, channel A saturates between 0.5 and 1.0 $\mu g/l$ with the signal decreasing to higher concentrations. Marginal response on channel A occurs at approximately 50 g/ . Channel B will alarm between 3 and 5 $\mu g/l$. Fall off of the B channel signal occurs between 100 and 150 $\mu g/l$. The dilution ratio of channel 'GB' could therefore be slightly increased with the alarm occurring at approximately 25 to 30 $\mu g/l$. This would also extend the upper range of channel 'GB'. Corresponding data for sensor module #19 is displayed in graph #74.

Graphs 75, 76 and 77 show the corresponding data of the three modified IDS detectors recorded during the field interference tests. The bar graphs indicate the signal level at the start of each interference test, with the arrowhead indicating the maximum response during each test. Some tests were started before the detectors had completely purged from the previous interference, which accounts for the scattering of the starting points between individual tests.

All of the interferences were placed upwind of the detectors ranging from 5 to 15 feet for some of the less volatile vapors and 30 to 100 feet for some of the smokes. The detectors were placed approximately two feet off the ground to assure good exposure.

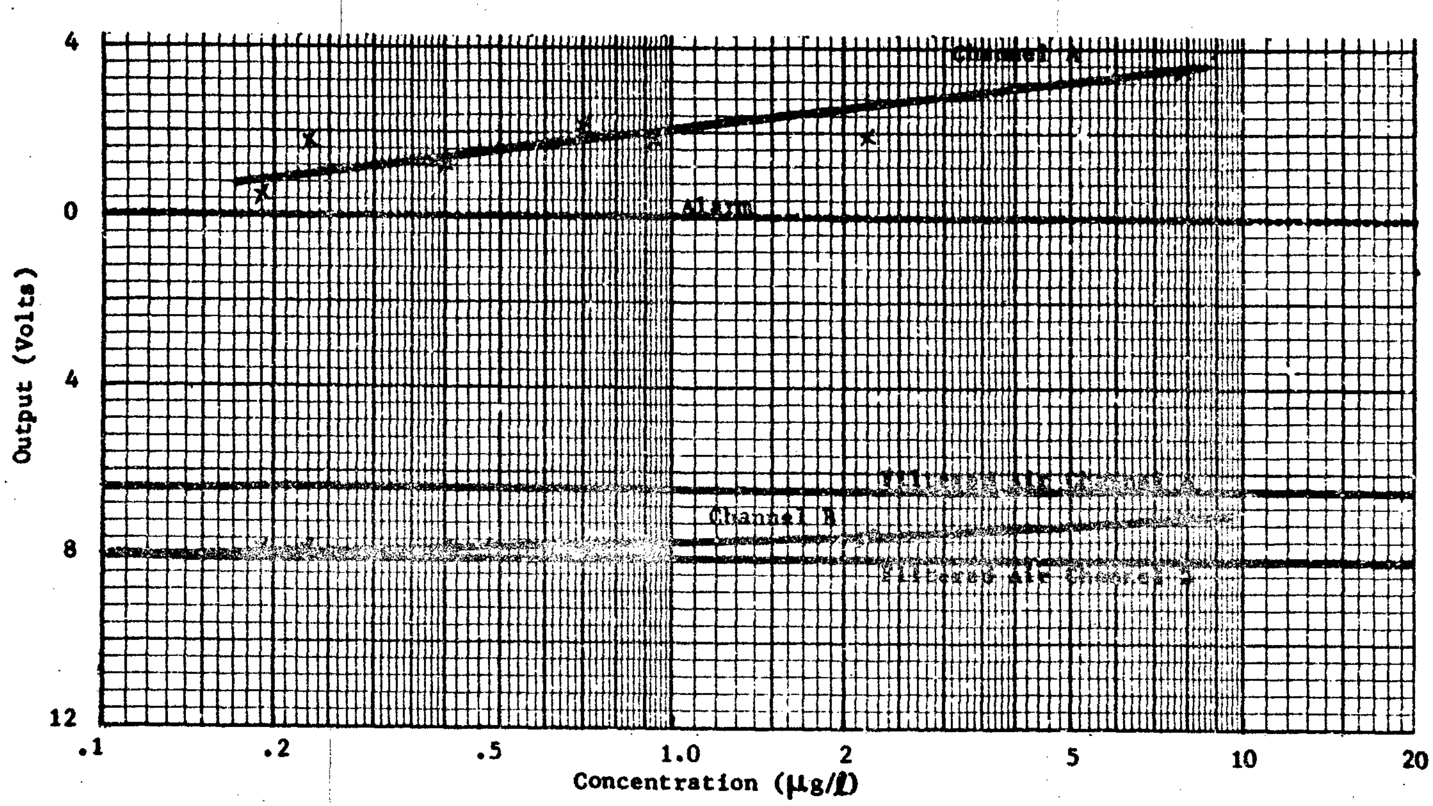



Figure 63. Response of Sensor Module #8 to O.W. Agent VX

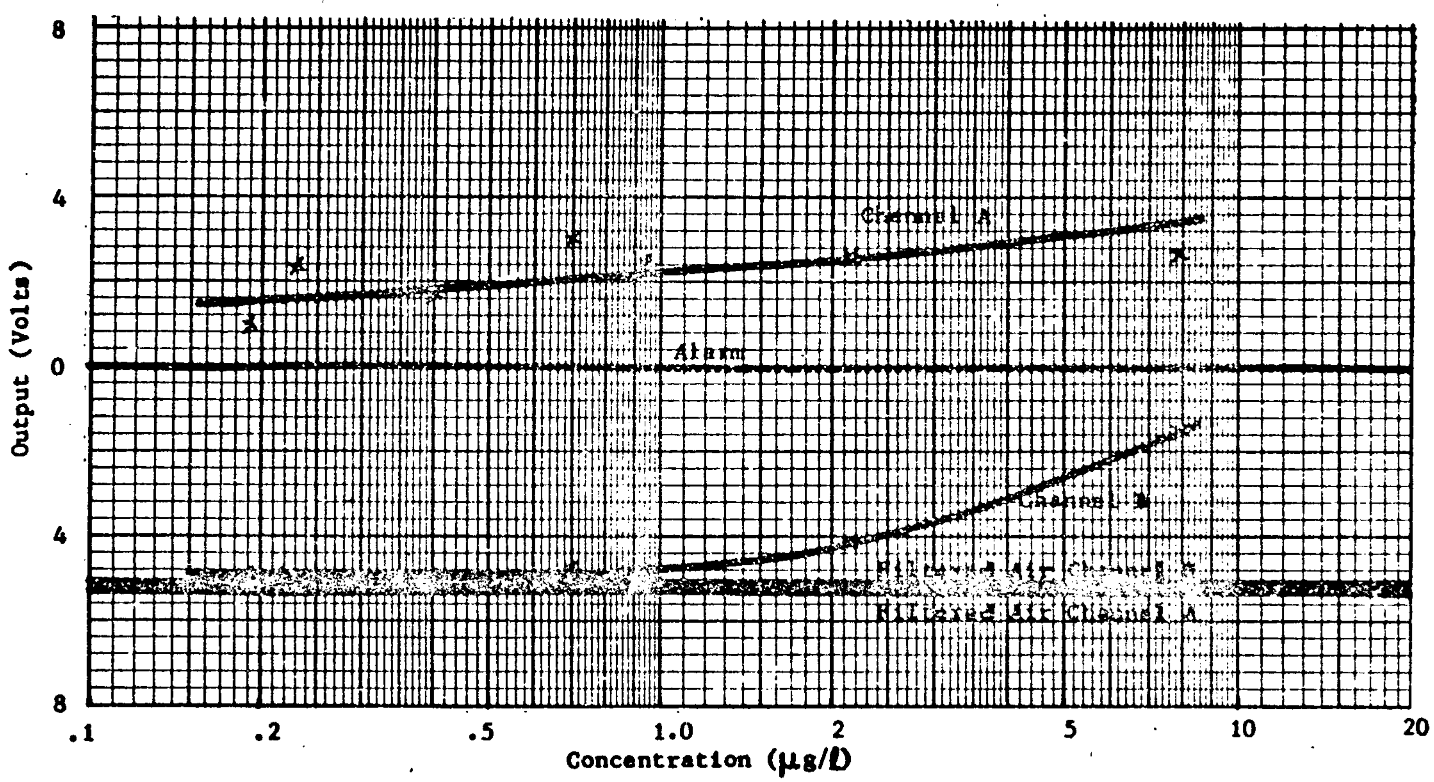



Figure 64. Response of Sensor Module #10 to C.W. agent VX

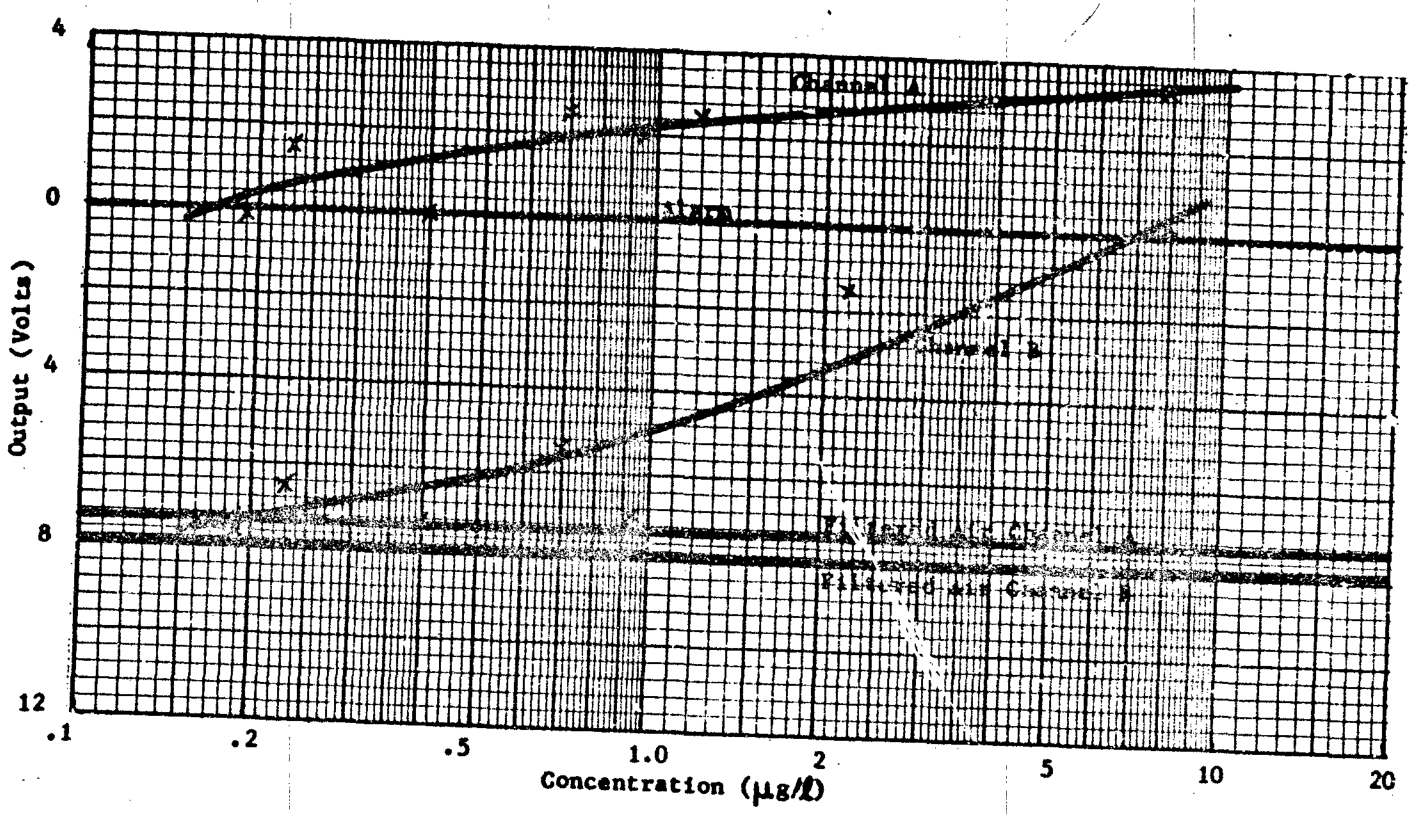



Figure 65. Response of Sensor Module #15 toC.W. Agent VX

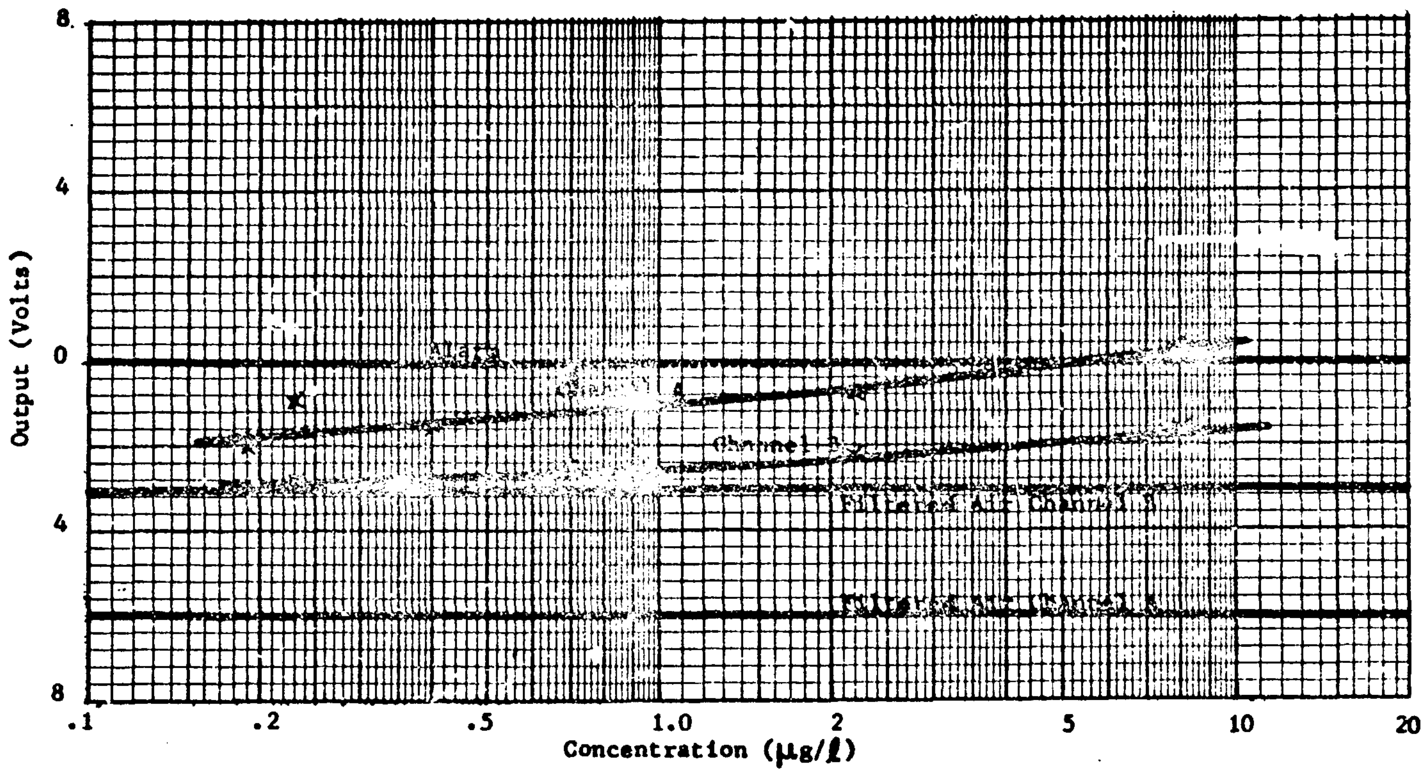



Figure 66. Response of Sensor Module #19 (unmodified) to C.W. Agent VX

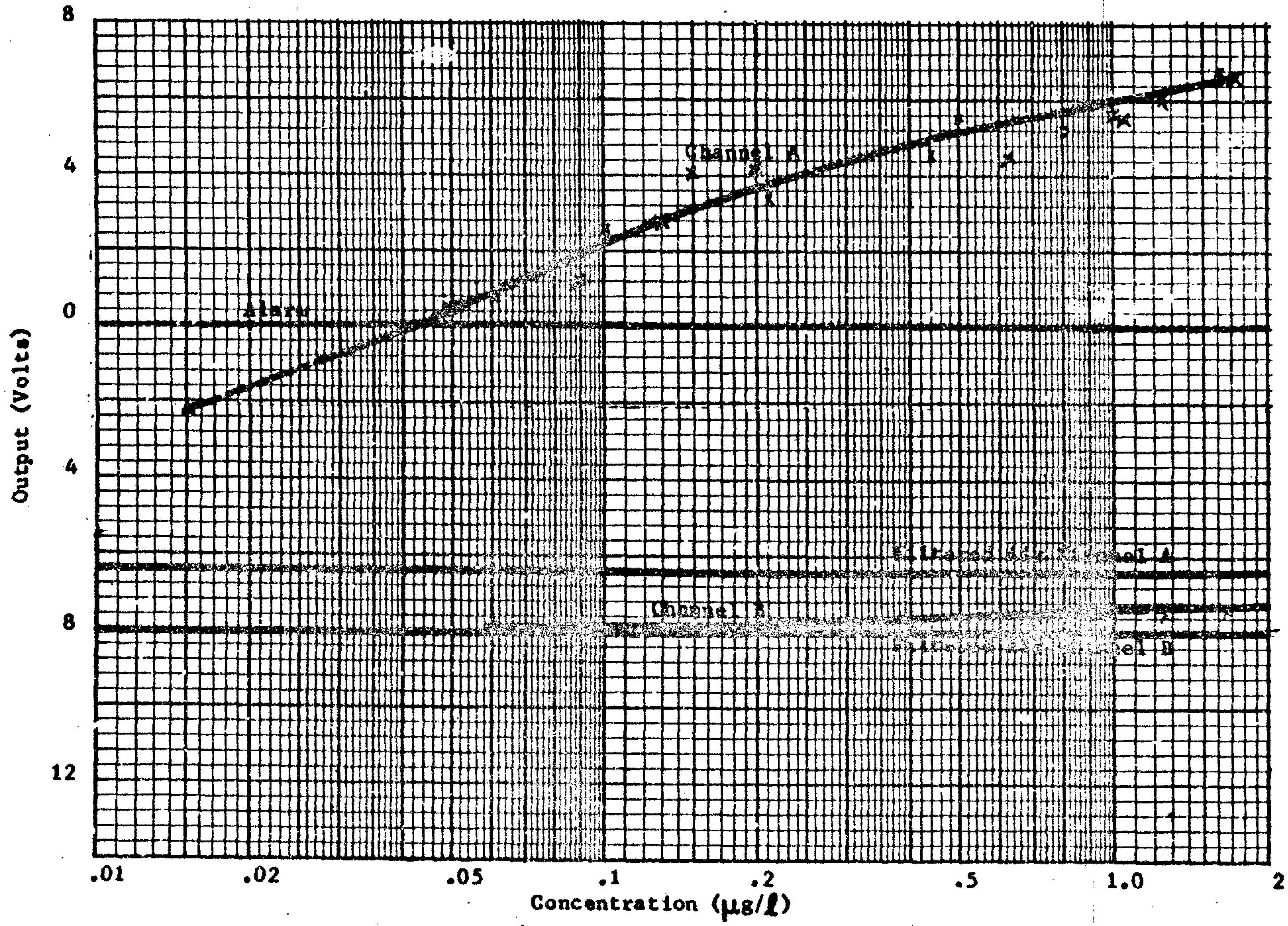



Figure 67. Response of Sensor Module #8 to C.W. Agent GB

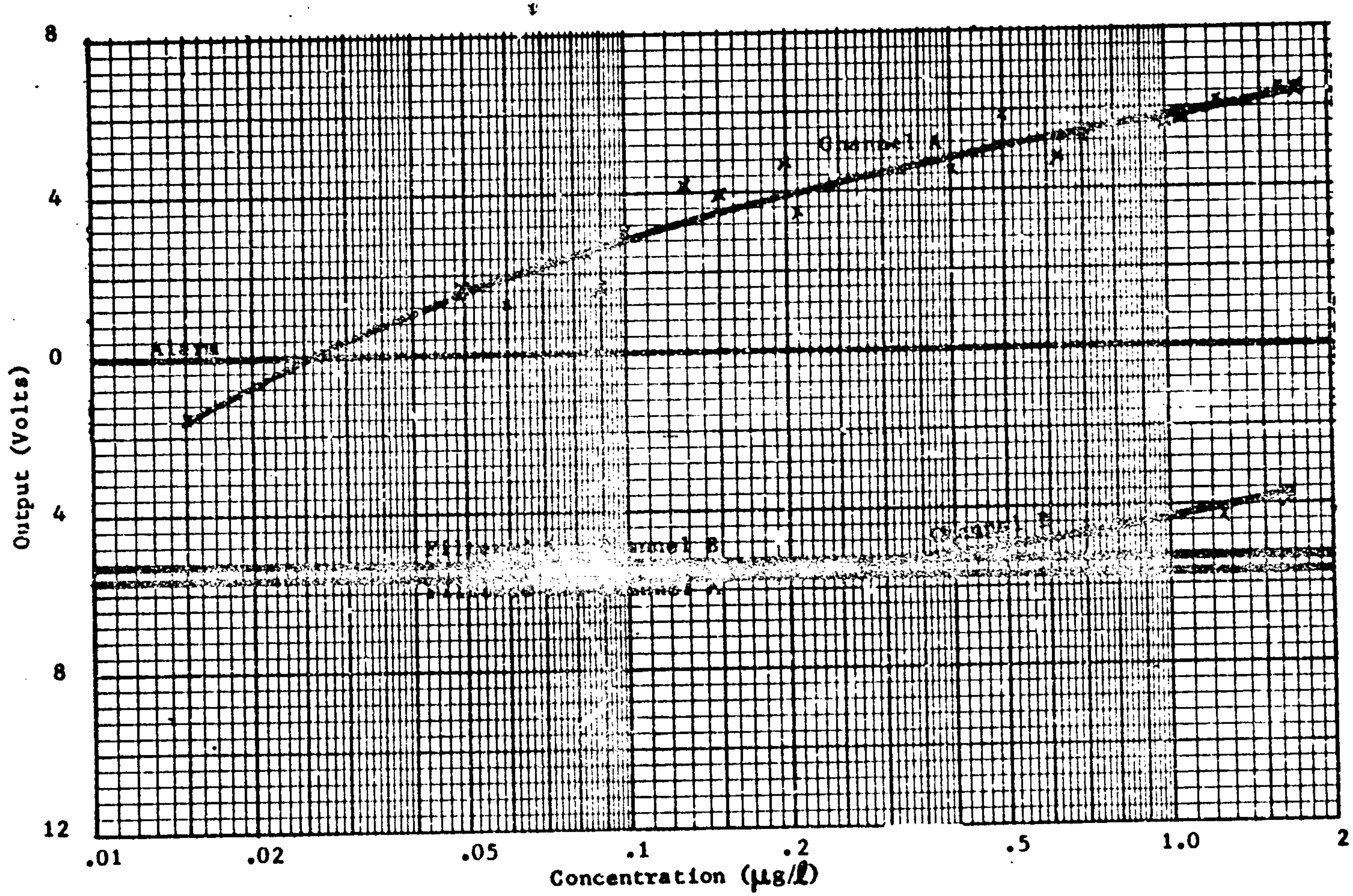



Figure 68. Response of Sensor Module #10 to C.W. Agent GB

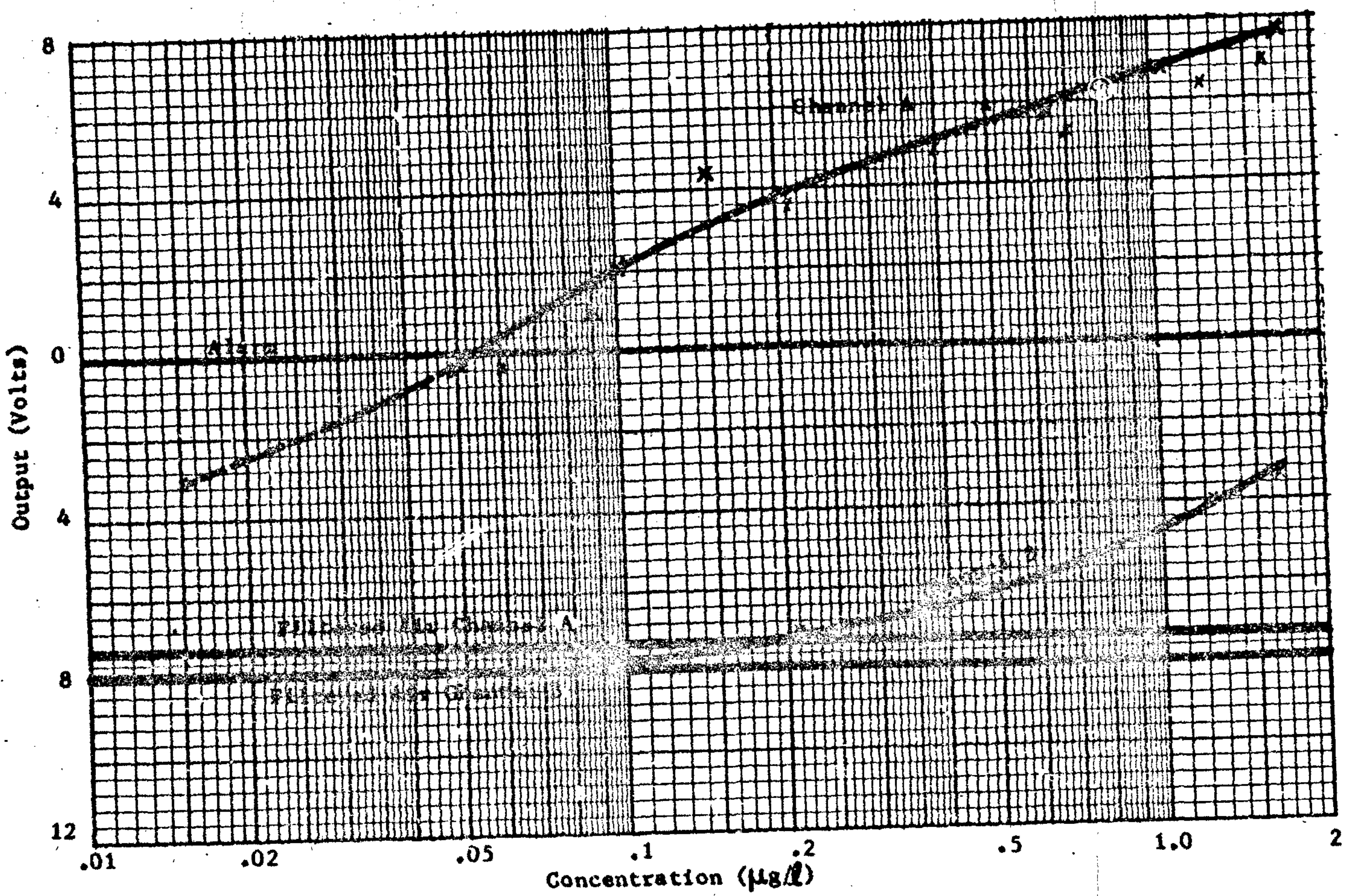



Figure 69. Response of Sensor Module #15 to C.W. Agent GB

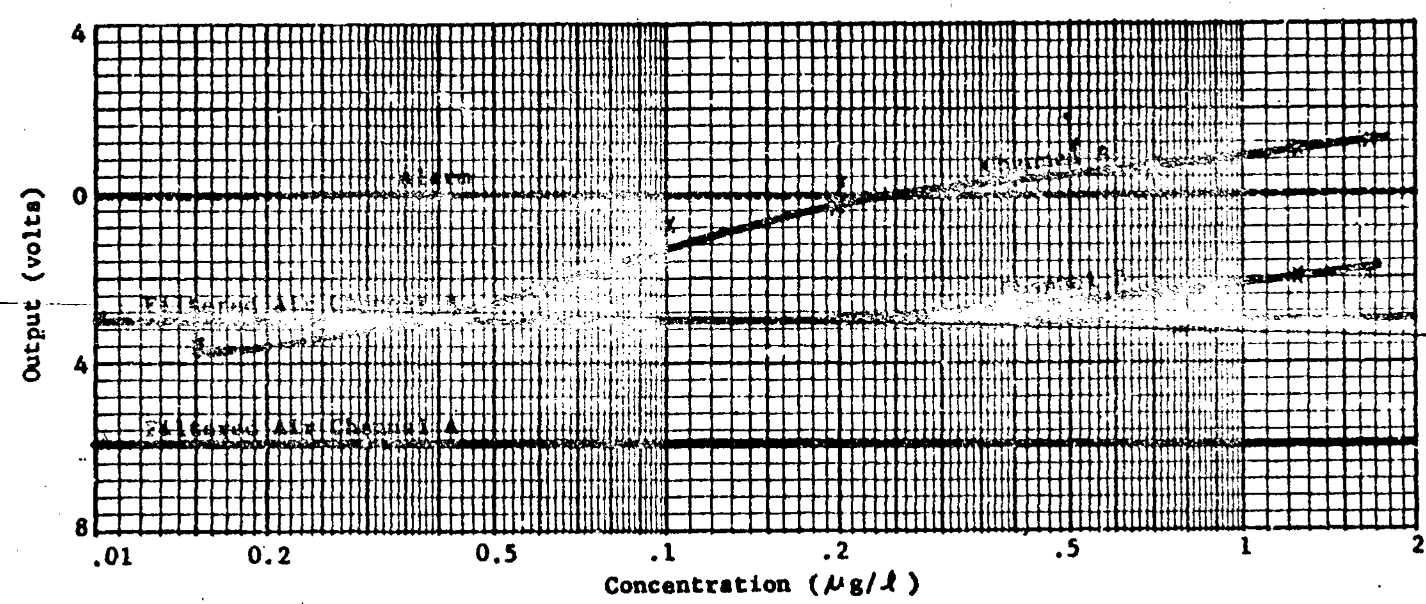



Figure 70. Response of Sensor Module #19 (unmodified) to C.W. Agent GB

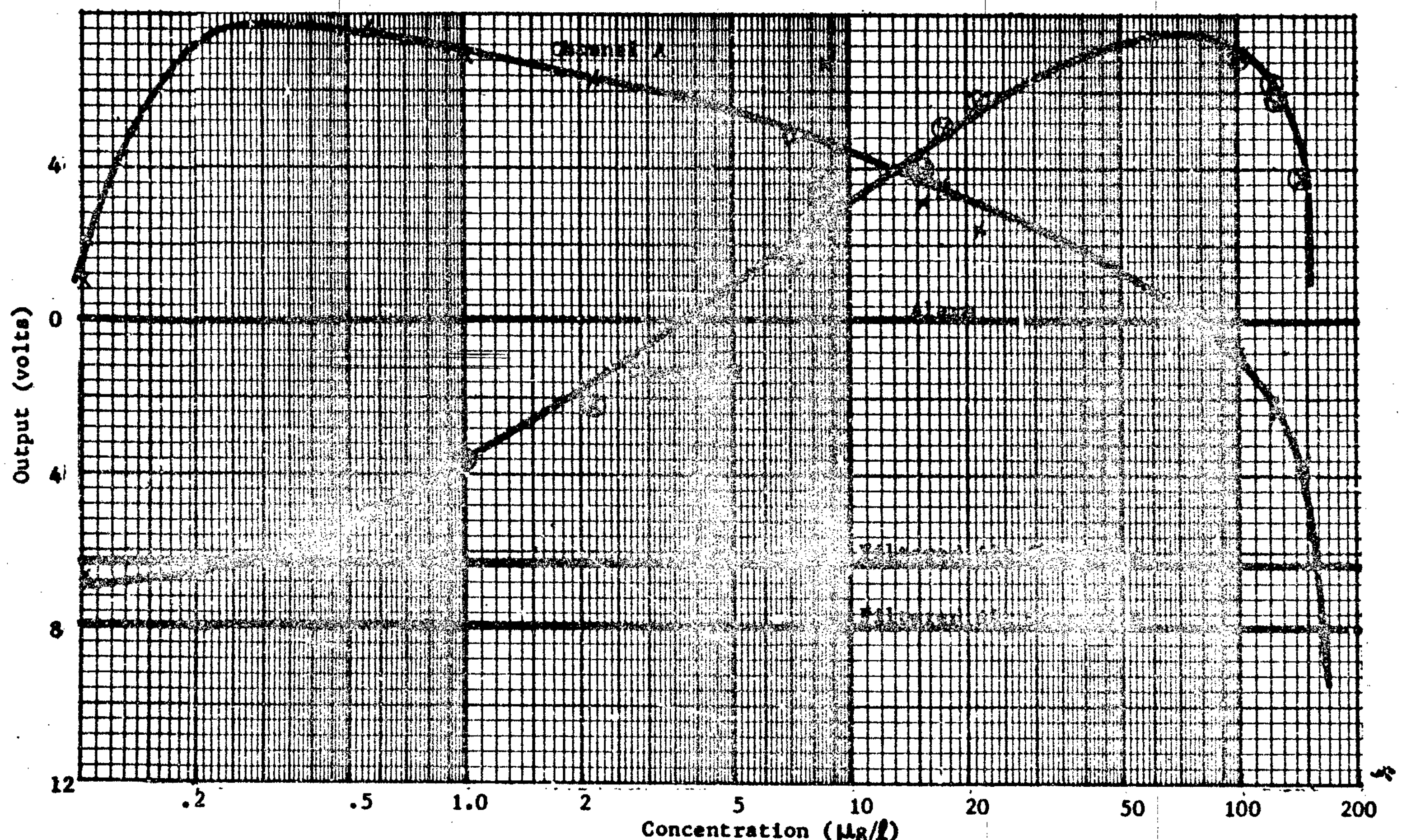



Figure 71. Response of Sensor Module #8 to C.W. Agent GA

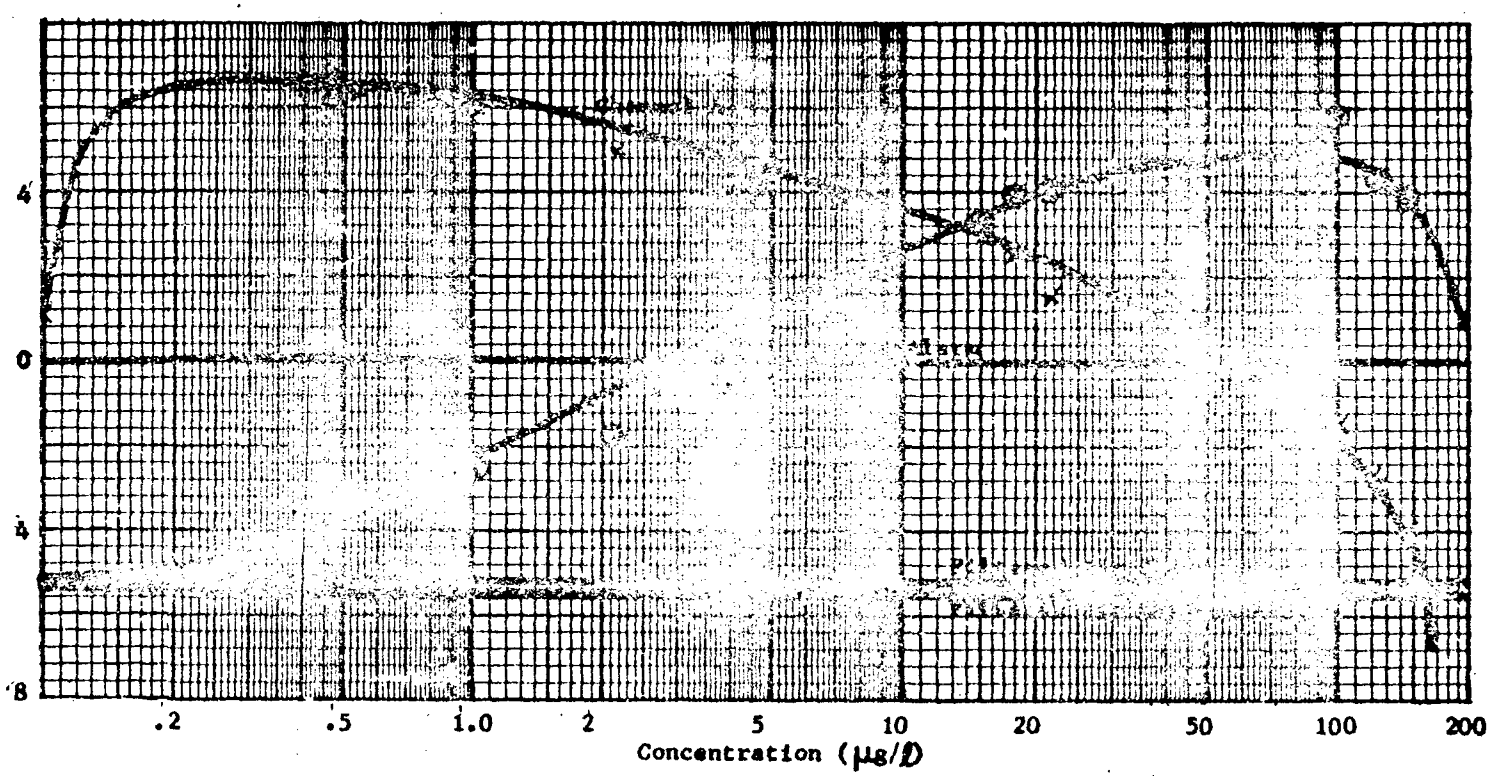



Figure 72. Response of Sensor Module #10 to C.W. Agent GA

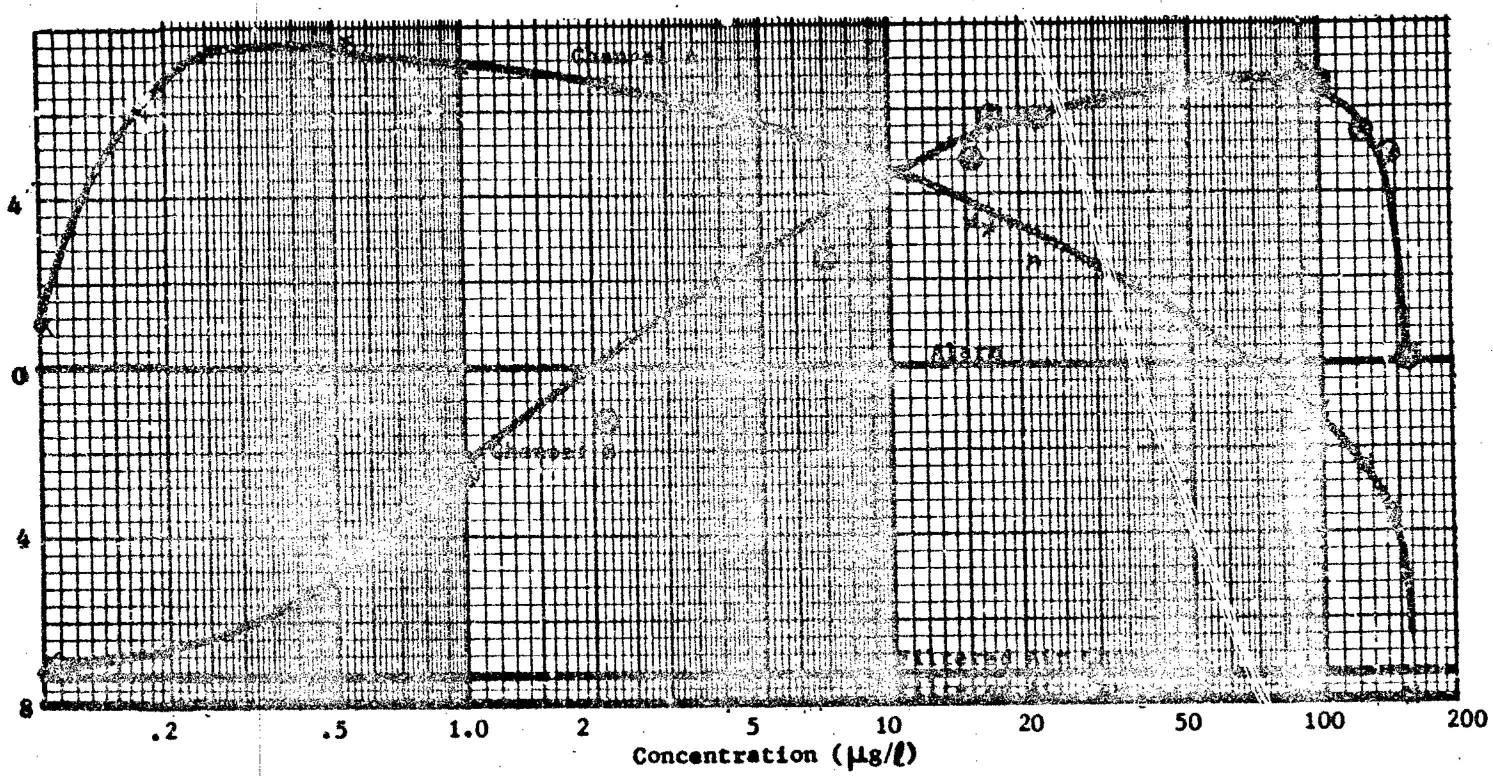



Figure 73. Response of Sensor Module #15 to C.W. Agent GA

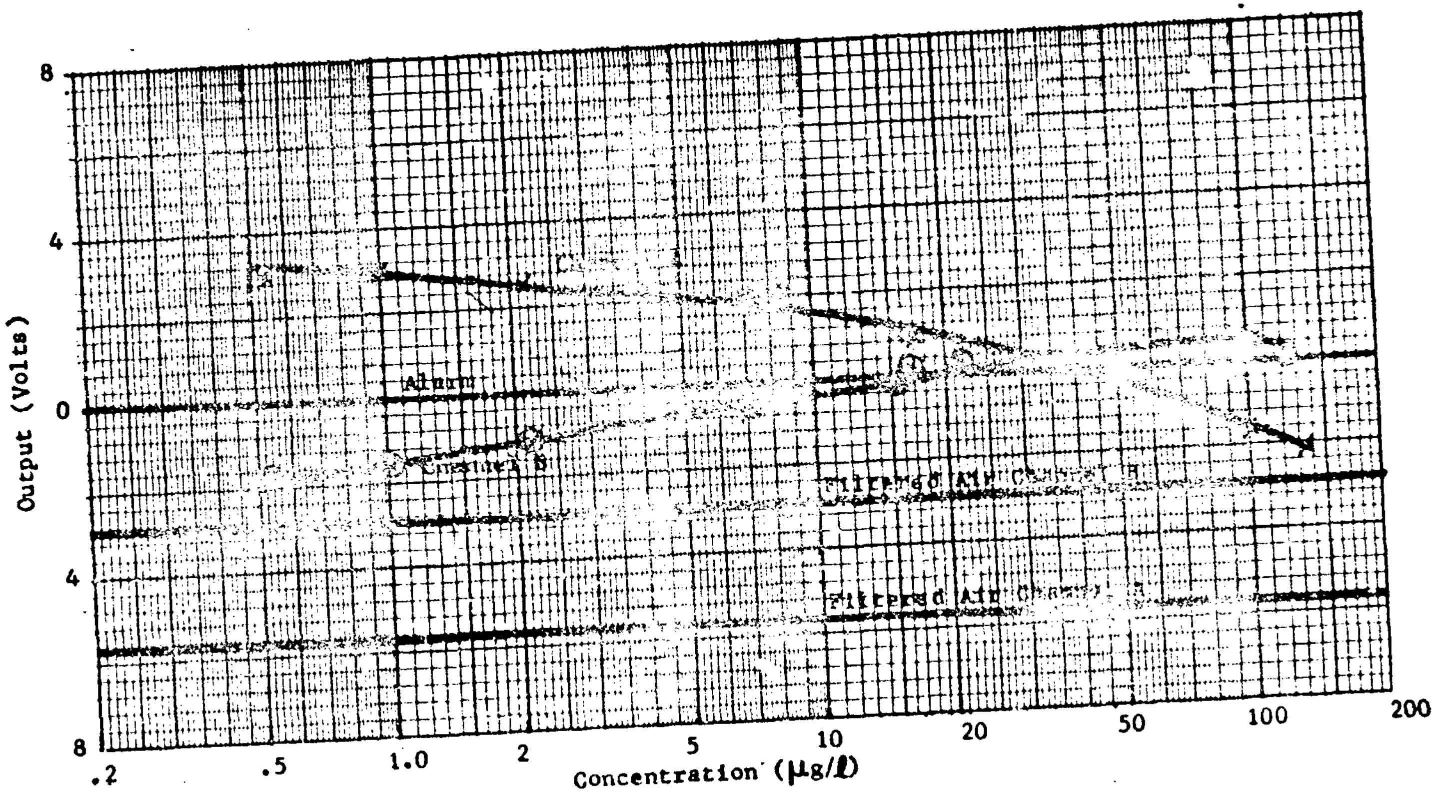



Figure 74. Response of Sensor Module #19 (unmodified) to C.W. Agent GA

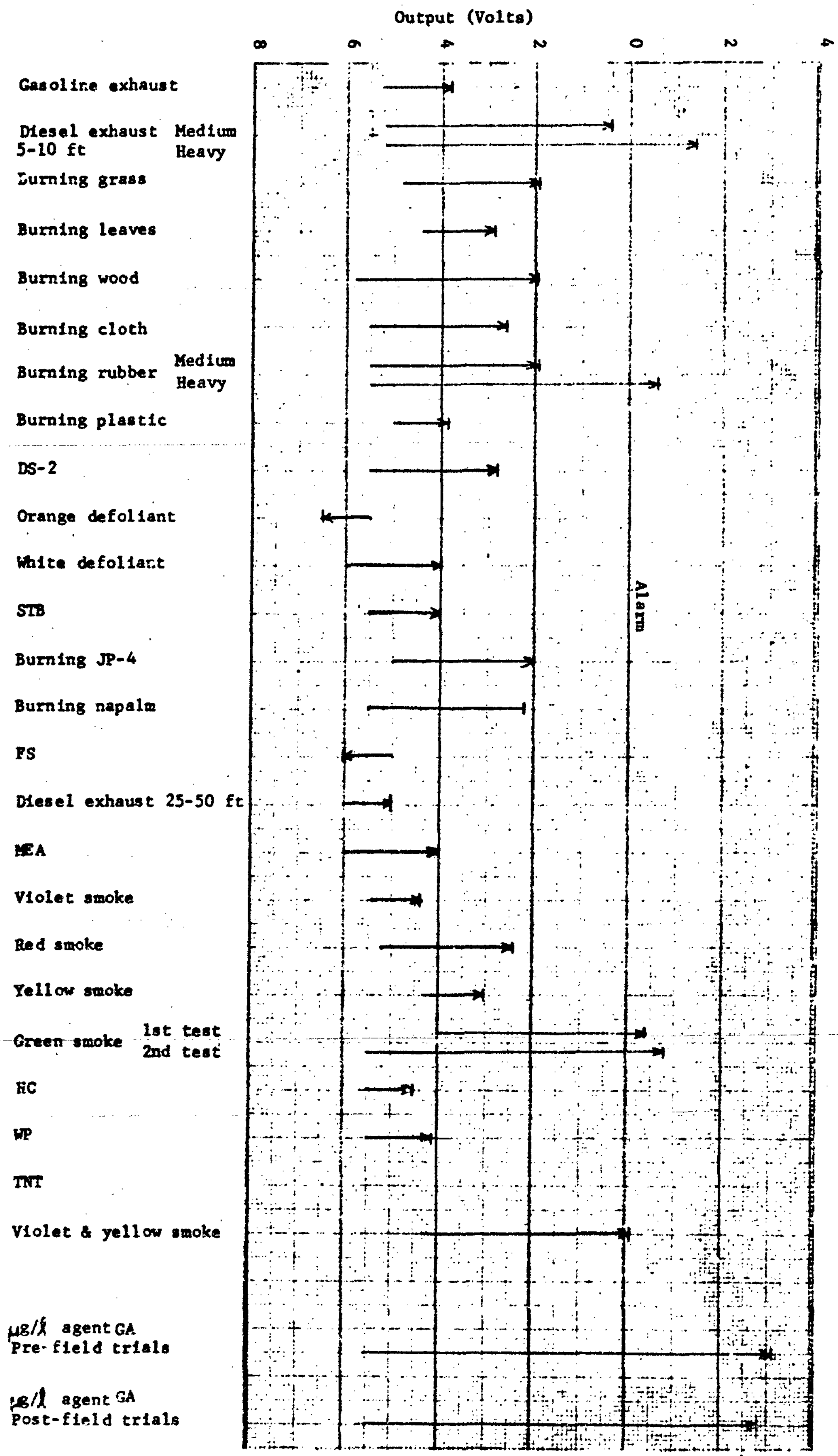



Figure 75. Field Test Results Sensor Module #8

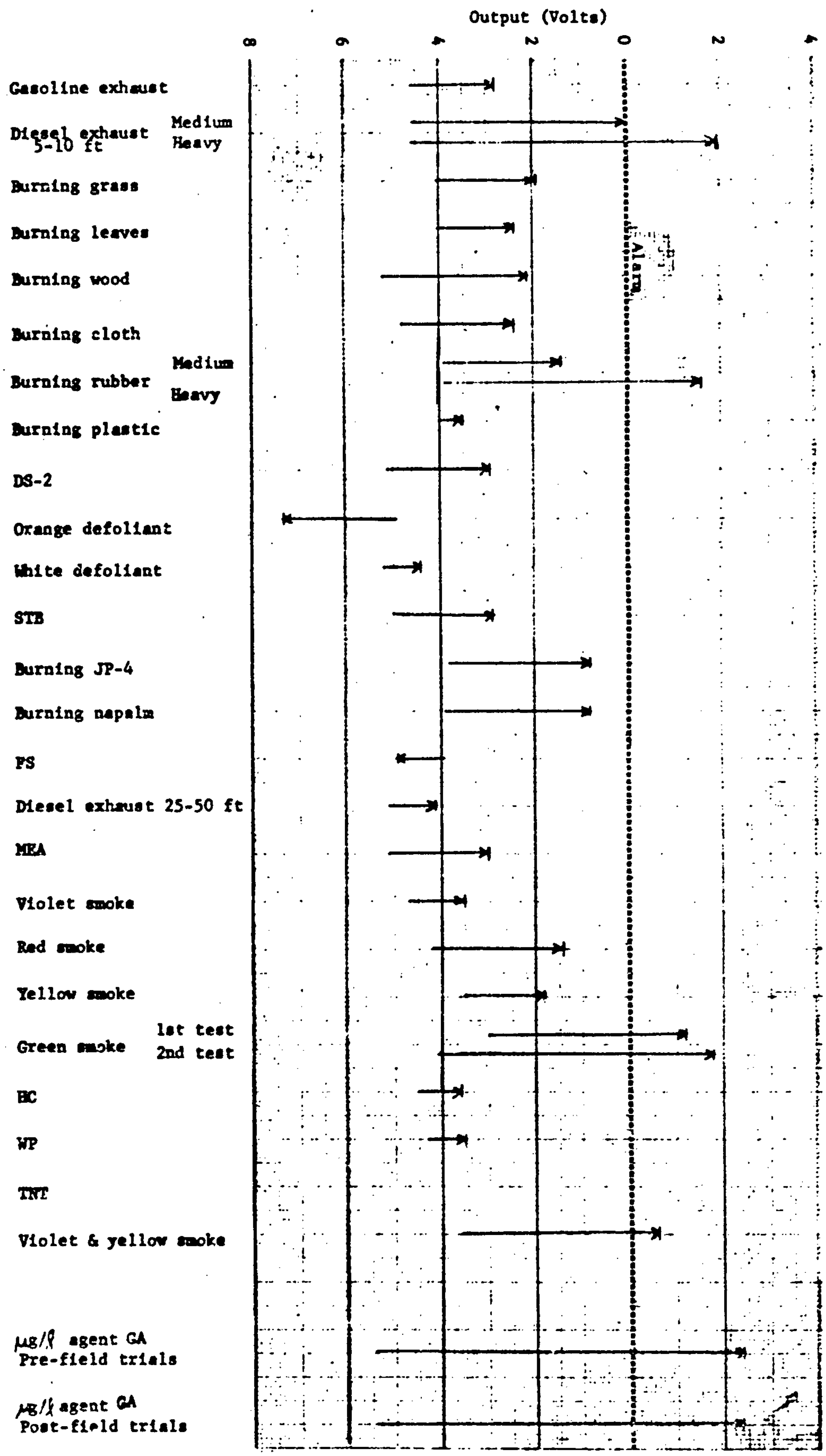



Figure 76. Field Test Results Sensor Module #10

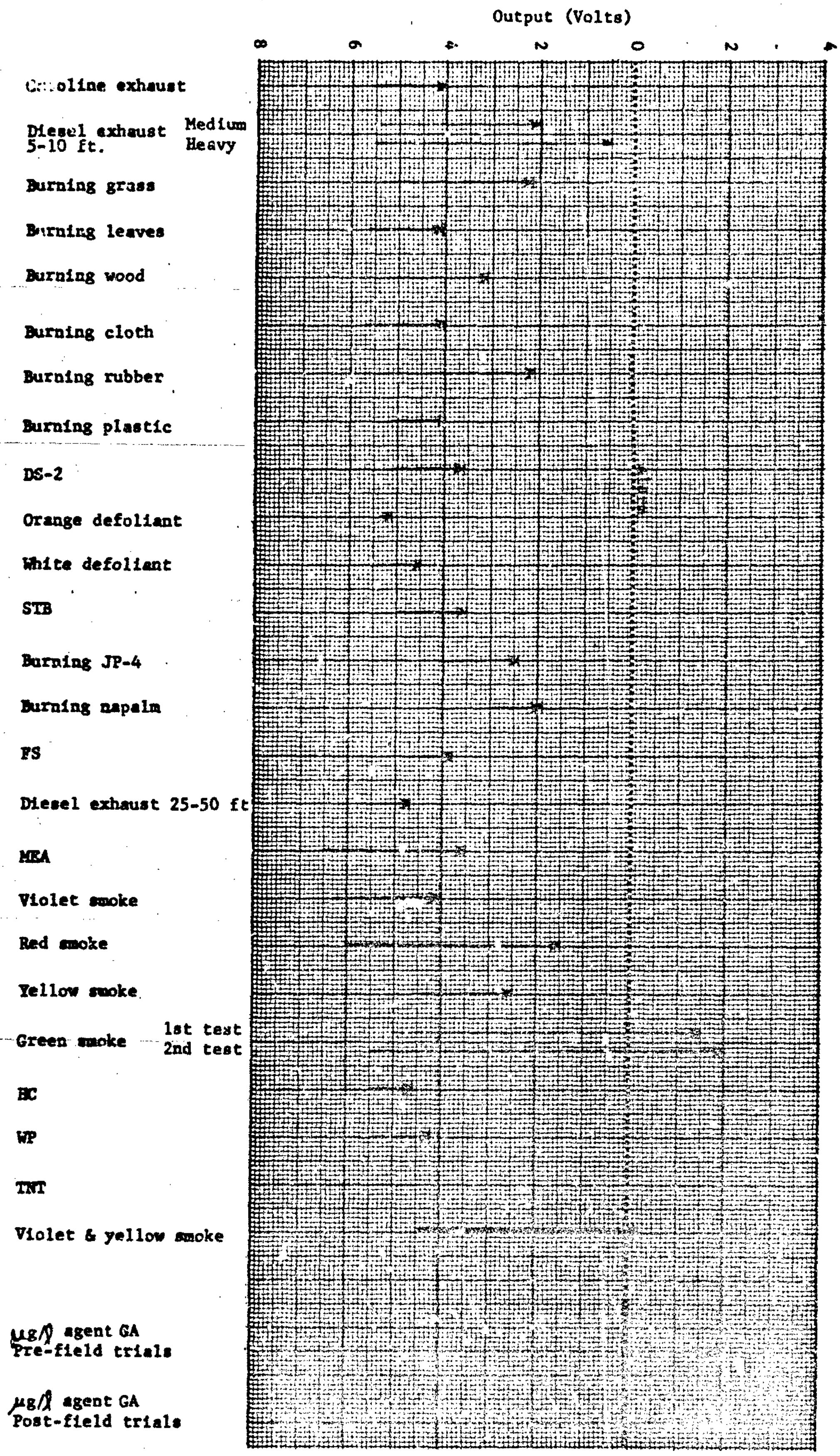



Figure 77. Field Test Results Sensor Module #15

Of the various potential interferences tested, three items caused false alarms. These included heavy concentration, of diesel exhaust, burning rubber and green signal smoke. Alarms to diesel exhaust would occur with a hose attached to the exhaust pipe of a 2 1/2 ton truck and the vapors directed at the detector from a range of 5 to 10 feet. As noted from the graphs, diesel exhaust tests were re-run with the truck at a range of 25 to 50 feet. No false alarms occurred during these tests. The response to burning rubber is shown by two bars. The peak response shown occurred once during an approximate 5 minute exposure. This peak represented an extremely heavy concentration of smoke. The green signal smoke test was conducted twice and is shown by two bars.

Also shown on these graphs are the IDS detector responses to 0.12 $\mu g/\ell$ of agent 'GA'. These responses represent agent exposures both prior to and after the field interference tests. No noticeable degradation in detector response was apparent due to the interference exposures.

## REFERENCES

1. Kahn, Lloyd and Marvin C. Goldberg "The Emanation of Tritium Gas from Two Electron-Capture Detectors," Journal of Gas Chromatography 3, 287-288 (August 1965).

2. Holden, A.V. and G.A. Wheatley, "Cleaning of Tritium Foil Electron Capture Detectors," Journal of Gas Chromatography 5, 373-376 (July 1967).

3. Shoemake, G.R.; D.C. Fenimore; and A. Zlatkis, "Radiation Sources for Ionization Detectors in Gas Chromatography," Journal of Gas Chromatography _ 285-286 (August 1965).

4. Handbook of Chemistry and Physics, 51st Edition, The Chemical Rubber Co., 18901 Cranwood Parkway, Cleveland, Ohio 44128, 1970-1971, p. B-247.

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## APPENDIXES





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APPENDIX A

MINIATURE PRECISION BEARINGS IDS BEARING-FAILURE ANALYSIS

MPB

Miniature Precision Bearings
DIVISION OF MPB CORPORATION
PRECISION PARK, KEENE, NEW HAMPSHIRE 03431
TELEPHONE: 603-352-0310
TWX: 710-366-1801

November 10, 1972

Honeywell Inc.
Systems & Research Division
2700 Ridgway Road
Minneapolis, Minnesota 55413

Attention: Mr. Willard E. Anderson
Principal Systems Scientist
Mail Station R2656

Dear Mr. Anderson:

We have examined the failed bearings and Brailsford motor which you sent us, and have also examined a complete motor and diaphragm pump assembly which was sent to us by Brailsford.

The S418FC bearings, which are mounted in the Scotch Yoke, appear to be the greatest source of difficulty. The failures which you returned to us had dried up lubricant in them, and were also very contaminated. Although this is a very difficult application for the bearings, we have several suggestions which should increase the life of these bearings.

1. The bearings should definitely be shielded, and possibly even sealed, if the torque available is sufficient to overcome the increased torque due to the seal drag.

2. Grease, or grease plate, should also be used. We would recommend Andok C grease if the temperature of the unit does not exceed 150°F, because of the superior channeling capabilities and low torque characteristics of this grease. However, if higher temperatures are anticipated, then we would recommend a higher temperature grease, such as Mobil 28.

3. The mounting arrangement of the bearings could also be improved to increase the life of the units. We note that the E-clip used to secure the inner rings on to the shaft, also rubs against the face of the outer ring. This, of course, adds friction to the unit, and could also generate debris which could get into the bearings.



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**Miniature Precision Bearings**
DIVISION OF MPB CORPORATION
PRECISION PARK, KEENE, NEW HAMPSHIRE 03431

November 10, 1972



4. The outer rings could be pressed into a sleeve so that the outers would act together as a roller. There could also be a shim between the outer races to reduce the end play and also help the alignment of the unit.

5. We would also recommend using Loctite on the shaft and in the sleeve to eliminate the slippage which is now occurring.

I have not seen any failures in the several S518FCHH rear bearings that we received and this is possibly because they are shielded. We suspect that any failures which you have had with this bearing would have occurred after the other bearings in the unit had failed.

We did see several failed S618CHN bearings and they were also due to lubrication failure and contamination. There was also evidence of a considerable amount of misalignment in one of these bearings.

We feel that the motor bearings should also be shielded and grease lubricated. The mounting arrangement should be redesigned to reduce the patented misalignment. We would recommend using steel liners in the plastic housing with preload springs to apply a light preload (approximately 8 ounces) to the bearings.

It appears that the lubrication failures which we have seen have been caused either by the heavy pounding loads which are causing the oil to break down, or contamination is getting into the bearing and destroying the lubricant. There does not appear to be any evidence of overheating present in the bearings. It is possible that a pressure differential is present in these motors and this could be causing evaporation of the oil lubricant.

A grease with its better load carrying capabilities, should improve the life of the units.

APPENDIX A

**Miniature Precision Bearings**
DIVISION OF MPB CORPORATION
PRECISION PARK, KEENE, NEW HAMPSHIRE 03431

November 10, 1972

Honeywell Inc. - page 3

We hope that the above comments will be helpful to you, and if we can be of any further assistance, please let us know.

Very truly yours,

Albert E Farrey
A. E. Farrey
Product Engineer

AEF:pa
cc: E. L. Burrichter
MPB Sales Engineer

APPENDIX A

APPENDIX B

VENDOR VISITS TO DISCUSS THE IDS BEARING PROBLEM

**Honeywell** Interoffice Correspondence

cc: Honeywell *D. Grier R2912
P. Johnson R3636
*C. Kaminski R3612
*B. Schluter R2656
MPB *G. Burrichter
*A. Farrey
R. Howe
*A. Lewis Peterson
Sperry W. Casaday
*J. Fields
R. Johnson
*F. Nardi

Date: 30 November 1972

To: E. T. Tromborg

From: *W. E. Anderson

Location: S&RC

Subject: Vendor Visits to Discuss the IDS Bearing Problem

ATTENDEES

Personnel from MPB, Sperry, and Honeywell held a meeting at Honeywell (Ridgway) Tuesday morning, November 28, to discuss the motor and pump bearing problem associated with the Ionization Detector System (IDS). Attendees are designated by asterisks above.

FAILURE ANALYSIS

Sperry brought a motor which I had sent to them after 555 hours of life testing since it was exhibiting what I judged to be the very earliest signs of bearing failure. Sperry then retested the motor for speed vs. torque to find its characteristics unchanged. But they did observe that the grease in the vicinity of the bearing at the output end of the shaft was black instead of the normally red Mobilgrease 28. Chemical tests during the meeting at Honeywell by Paul Johnson of Materials Engineering (with Sperry, MPB, and other Honeywell personnel present) showed the wear debris to be not iron but aluminum/aluminum oxide. The source of the wear debris was an aluminum spacer or sleeve on the rotor shaft between the end of the rotor and the end of the inner race of the output bearing. Evidently this sleeve was sliding axially on the shaft or turning on the shaft to cause wear debris.

A summary of the meeting with respect to a solution of the IDS motor/pump bearing problem, as agreed to by all present, follows.

MOTOR IMPROVEMENT

The lubricant should continue to be Mobilgrease 28. The bearings for the motor should be MPB's bearing no. SR2AMCKHH5P58LY-231 (20.% fill)[1] except that for immediate correction, the unused bearings presently stocked by Sperry (fully open bearings) should be returned to MPB for



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installation of double shields as a no-cost customer service. These bearings would then be MPB's bearing no. SR2AMCXHH5P28LY-231 (20.% fill). Bearing seals (ZZ vs. HH) were judged impracticable and unnecessary at this time due to fabrication problems and lack of demonstration of need. Seals can be employed at a later time with this bearing design if desirable.

Loctite, probably Loctite 601, is to be used "throughout" the motor to eliminate all diametral clearances and, by employing a one-pound dead weight on the outer race of the bearing at the circuit end of the motor during the Loctite curing process (24 hours at room temp. for Loctite 601), to preload the motor bearings. Loctite 601 can be used in diametral clearances from line-to-line (MPB's experience) to 0.003" (Loctite's max. recommended diametral clearance for specification strength--see attachment TDS #30B). To preserve the alignment of the rotor and the field poles, diametral clearances should be a nominal 0.0005" ± 0.0002" considering both appropriate motor and bearing diameters and tolerances. For example, the O.D. of an SR2A bearing is 0.5000" + 0.0000", - 0.0002"; thus the bore in this case should be 0.5003" + 0.0002", - 0.0000". Such dimensioning will permit retention of alignment as indicated as well as ensure that the force opposing the one-pound dead weight will be through the bearings to preload them and not by, for example, outer race hang-up in the race retaining bore. The material of the sleeve on the shaft is to be changed from aluminum to 300 series stainless steel and it, too, is to be Loctited to the shaft for curing during the preloading operation.

This was not mentioned at the meeting, but great care must be taken to keep Loctite out of the bearings. At Honeywell, excess Loctite is removed (if ever used in excess) by use of tweezers and sponge under low magnification by a skilled technician.

The motor shaft end play is to be determined after full cure of the Loctite used in the preloading operation. The method agreed upon is to apply a force of 8 ounces to the shaft in one direction followed by a force of 8 ounces in the opposite direction. The resulting total end play is to be a maximum of 0.0005" (0.5 mil), which was judged to be an easy specification for Sperry to achieve.

ECCENTRIC IMPROVEMENT

The Scotch yoke as it now exists should not be used. If it is to be used, it should be lined with steel. The two eccentric bearings should be mounted in a steel sleeve and preloaded.

The magnesium rod and eccentric assembly employing P13 bearings was judged to be a great improvement over the Scotch yoke. Even P00 bearings can be supplied by MPB if necessary.

APPENDIX B

Since every bit of improvement is desirable, the recommendation was to employ the magnesium rod and eccentric assembly employing the two duplex pairs of preloaded bearings.

The eccentric bearings are to be lubricated with Mobilgrease 28, plated, MPB's designation LYF-231.

FINAL NOTE

Gentlemen, it is generally agreed that this was a very productive meeting. With cooperation of this sort we're certain to quickly solve the IDS motor/pump bearing problem. I thank you for your attendance and assistance with this problem. If you disagree with anything in this memo, please speak up fast! **

Willard E. Anderson

Willard E. Anderson
Principal Systems Scientist
Honeywell Inc.
S&RC, M.S. R2656
2700 Ridgway Parkway
Minneapolis, Minn. 55413
(612) 331-4141, ext. 5994

FOOTNOTE

1 In this number, "S" denotes AISI 440C stainless steel; "R2A" is the basic bearing size with "A" denoting a larger diameter and wider unit than the R2; "MCX" denotes a molded, glass-filled, Teflon retainer; "HH" denotes double shields; "5" denotes the tolerance, here ABEC 5P; "P58" denotes the radial play, here 0.0005" to 0.0008" to provide for a relatively large contact angle upon preloading to favor passage by the IDS package of mechanical shock tests; "LY-231" denotes Mobilgrease 28; and "(20% fill)" denotes the amount of grease to be added.

** As of January 3, 1973, I've had only positive feedback. W.E.A. 1/3/1973

APPENDIX B

APPENDIX C

LOCTITE TECHNICAL DATA SHEET

LOCTITE

TECHNICAL DATA SHEET

TDS#30B

# 601
# ADHESIVE/SEALANT
## (HIGH STRENGTH)
## AUGMENTS PRESS FITS
## (MEETS MIL-R-46082A (MR) TYPE I)

## I. PRODUCT DESCRIPTION

A single component, liquid adhesive for supplementing press fits or bonding of slip-fitted cylindrical parts, which operate at temperatures up to 300°F. Like other Loctite adhesive/sealants, the material will cure in seconds when applied to parts preheated to 250°F. In addition, the faster cure characteristics of Loctite 601, will fixture most metal surfaces at room temperature without the use of Locquic Primer.

## II. NEW PRODUCT BENEFITS

A single component, liquid adhesive/sealant with improved speed of cure. On most metal surfaces, Locquic Primers/Activators are not required to obtain maximum retaining strength. However, all surfaces must be cleaned to obtain maximum retaining strength.

## III. APPLICATION AREAS

Loctite 601 is used to assemble fitted parts; replacing or augmenting press fits; knurls, splines, keys, pins, etc. The faster room temperature cure characteristics of this improved adhesive provide a general purpose compound which is used to simplify production-line methods and permit faster field repair of difficult to assemble parts.

IN PRODUCTION ASSEMBLY – the benefit of stress free mounting and reduced machining costs can now be realized with 601 when bonding parts including oil-impregnated powdered metals; stainless steel; and oxide coated surfaces. Production methods include fast fixturing in 10 seconds and full cure in 5-20 minutes with heat or Locquic Primer. At room temperature, fixturing time is 10 minutes with full cure developing in 24 hours.

FOR MAINTENANCE AND REPAIR – with minimum down-time and reduced cost use 601 to repair or replace shaft mounted parts.

Typical Use Areas

1. Electric motor rotors on shafts.
2. Gears, pulleys, sleeves, bushings, etc.
3. Oil Seals in Housings.
4. Pins and dowels.
5. Bearings and bearing races.



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## IV. TYPICAL PRODUCT PROPERTIES*

### A. Properties in Liquid State

Color .................................... Green and Fluorescent

Viscosity .................................... 125 ± 20%; cP

Shelf Life .................................... 1 Year Minimum

### B. Cured Physical Properties*

| Strength Time after: Cure Time/Temperature | Shear Strength, PSI (Tested at Room Temperature) |
|---|---|
| 24 hrs. @ 75°F | 3000 |
| 72 hrs. @ 75°F | 3500 |
| 1 hrs. @ 200°F | 3500 |

| Shear Strength at Temp. (24 hrs. Room Temp. Cure) | Shear Strength PSI (Tested at temp.) |
|---|---|
| 200°F | 2500 |
| 300°F | 1200 |
| 400°F | (RC #40 recommended for temp. above 300°F) |

Operating Range -65°F to +300°F

| Bond Line Thickness | Specification Strength | Sealing |
|---|---|---|
| (Max. Diametrical Clearance for) | .003" | .005" |

Solvent Resistance

(Specimens cured 24 hours at 75°F, then immersed in solvents for 168 hours at 188°F.)

| Chemical | Shear Strength as % of Air References (tested at room temperature) |
|---|---|
| Air @ 188°F (reference 4900 psi) ** | 100 |
| Water | 40 |
| Toluene | 70 |
| JP-4 | 100 |
| Alcohol | 96 |
| Glycol & Water | 50 |
| MIL Type #6 Test Oil | 100 |

Loctite 601 has excellent solvent resistance with most fluids. Water and water based solvents cause loss of strength as indicated by above data. Applications subject to high humidity or water (at temp. 150°F plus) should be evaluated under actual operating conditions before specifying.

* Test values obtained on pins and collars as specified in Mil-R-46082A (MR) without Locquic Primer.

** Because of long term heat age, air reference value of 4900 psi is greater than typical room temperature cure values for 601.

APPENDIX C

C. Typical Cure Characteristics *

Cure Speed: (tested on 1020 steel surfaces)

| Temp. | Method | Time | Shear Strength, PSI (tested at Room Temp.) |
|---|---|---|---|
| (1) 75°F | No Primer | 10 min. | Fixturing (over 50 PSI) |
| | | 15 min. | 400 |
| | | 30 min. | 2000 |
| | | 60 min. | 2500 |
| | | 6 hrs. | 2700 |
| (2) 75°F | Primer T * | 5 min. | Fixturing (over 50 PSI) |
| | | 10 min. | 2500 |
| | Primer NF * | 10 sec. | Fixturing (over 50 PSI) |
| | | 5 min. | 2500 |
| (3) Preheated parts 250°F | No Primer | Latent heat of parts will usually cure the material before the parts return to room temperature. | |
| (4) Heat Cure (200°F at bond line) | No Primer | 15-20 min. | 2500 |

* Primer generally not required for most surfaces. Surface conditions affect the cure of Retaining Compounds. Certain plated, hardened, and plastic parts have lesser surface activity and the use of Locquic Primer will increase initial cure speed.

# V. SURFACE PREPARATION

Parts must be clean and dry. Vapor phase cleaning or washing in a chlorinated solvent is usually sufficient.

# VI APPLICATION METHOD

Cure method and assembly technique should be developed to suit the application. Considerations may be given to the faster room temperature cure characteristics available in this product, without the use of Locquic Primer.

This material can be easily dispensed with the Loctite Model 50 Handgun Applicator, standard Loctite Automatic Application Equipment, or simple techniques such as roll coating, brushing or wiping. For complete information on Automatic Applicators, request Loctite Bulletins #470, #470-2, #471 and #492.

## VII. CORROSIVITY

Loctite Adhesive/Sealants are slightly acidic and may stain or discolor some metals, especially those containing copper. However, the effect and performance of the adhesive is usually inconsequential.

## VIII. CAUTION

Excessive or repeated skin contact with Loctite anaerobic adhesives and sealants may cause dermatitis in sensitive persons. In case of skin contact, remove promptly by washing. In case of skin reaction, discontinue contact with product. If skin reaction persists, see a physician. To avoid skin contact, use the applicator nozzle provided. Other applicators are available from Loctite Corporation.

## IX. SPECIFICATIONS

The properties listed in this data sheet are typical and should not be used as a basis for preparing specifications. Please contact the Loctite Corporation, Newington, Connecticut, for assistance and recommendations on specific specification limits to this product.

## X. STORAGE CONDITIONS

Store material in original containers with proper fill to provide adequate air space to maintain the anaerobic liquid state. Maintain at 68 °F ±20 °F for maximum shelf life. When stored under these conditions, a one year shelf life may be expected. Material removed from containers may become contaminated during use. Do not return remaining liquid to original containers.

LOCTITE CORPORATION
NEWINGTON, CONN. 06111 TEL. 203 278-1280
LOCTITE CANADA LTD., MISSISSAUGA, ONT



APPENDIX C

APPENDIX D

LETTER MAILED TO THIRTY PUMP MANUFACTURERS

# HONEYWELL

INC.

Gentlemen:

By virtue of past and present contracts with the U. S. Army and U. S. Air Force, we have need for a pump/motor combination for a point sampler in a trace gas detection system. The requirement is for a vacuum pump capable of pulling 5 liters/min. of air flow (NTP) with 40 inches of water pressure drop. The pump/motor should have a life approaching 10,000 hours mean time between failures.

We have two approaches in our development program. The preferred and presently existing system utilizes a 30 VDC motor drawing approximately 100 milliamperes of current for very high efficiency. The space available is 5 1/8" x 3 7/8" x 1 5/8". In this application, the system should be able to start at -60°F. (Locked rotor current could be used to heat the motor and bearings if necessary if the pump/motor would not be damaged.) Several minutes after starting, the entire pump/motor combination would be in a thermostatically controlled ambient environment with a temperature of +140°F continuously, generally.

We have experienced life problems with the above approach. While we are working to solve these problems, we desire to pursue in parallel another approach. The second approach is to employ a rugged pump/motor combination operating on 115 or 230 VAC which has been shown to have an adequate life. Such a pump/motor must fit into a volume given approximately by 5 3/4" x 5 3/4" x 3". This volume will not be thermostatically controlled, so except for transformer heat, pump/motor heat, etc., the ambient temperature will range between the extremes considered by the military: -60°F and +140°F.

Please provide me with comprehensive information on your pump/motor combination in the above two categories.

Sincerely,

Willard E. Anderson

Willard E. Anderson
Prin. Research Scientist/Engr.
Mail Station: R2656
Extension: 5994

WEA/bjt



AEROSPACE & DEFENSE GROUP

SYSTEMS & RESEARCH DIVISION • 2700 RIDGWAY ROAD, MINNEAPOLIS, MINNESOTA 55413 • 612/331-4141

Honeywell

4 May 1973

RPC Corporation
1222 East Grand Avenue
El Segundo, California 90245

Attention: Mr. Bill Barmore

Hello Bill:

I am enclosing information you requested in our phone conversation April 30, 1973. This is not an order but is material preparatory to any possible order.

We are interested in a reliable motor/pump assembly. Our goal is 10,000 hours MTBF. We'll be satisfied with a shorter MTBF if necessary, but if you design for 10,000 we may obtain a smaller, yet satisfactory MTBF.

Our design goal is to pump by suction up to 5 normal liters/minute through our instrument by reducing the pressure at its outlet by up to 40 inches of water from atmospheric pressure. Our present pumps operate at speeds less than 4000 rpm (usually less than 3500 rpm), draw a current less than 150 mADC, and require a voltage less than 29 VDC. If you will be considering either of the two motors we use (EAD and Sperry), call me for factory contacts in the likely event the motor characteristics must be altered. Efficient motor/pump operation, hence low power operation, is an important factor for our battery-powered version of the instrument. The motors we use are expensive, at least during this developmental phase, so reliability, cost and power trade-offs are considerations. Perhaps a long-life DC brush (not brushless) motor such as you use would be a better choice.

We have not yet completed life tests on vane pumps, however we do have one of your units (9004) in operation. Our information from people who have tested them is that vane pumps are generally unsatisfactory. Hence, please bias your thoughts and designs of the first generation pump to circumvent possible problems.

Sincerely,

Willard E. Anderson

Willard E. Anderson
Principal Systems Scientist
Mail Station R2656
Phone (612) 331-4141, ext. 4667

WEA/njg

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SYSTEMS & RESEARCH CENTER AEROSPACE & DEFENSE GROUP
2600 RIDGWAY PARKWAY, MINNEAPOLIS, MINNESOTA 55413 TELEPHONE 612/331-4141

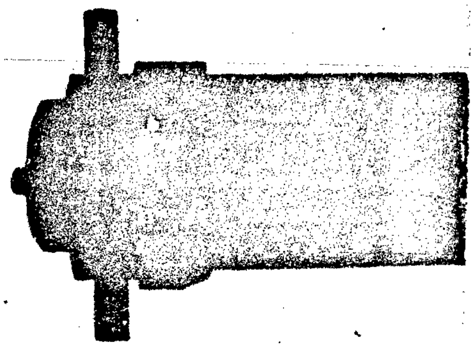
## RPC MINIATURE GAS SAMPLING PUMP

### Model 9004

**DC OPERATION** **LOW MAINTENANCE**

**PULSATION-FREE FLOW** **LONG LIFE**

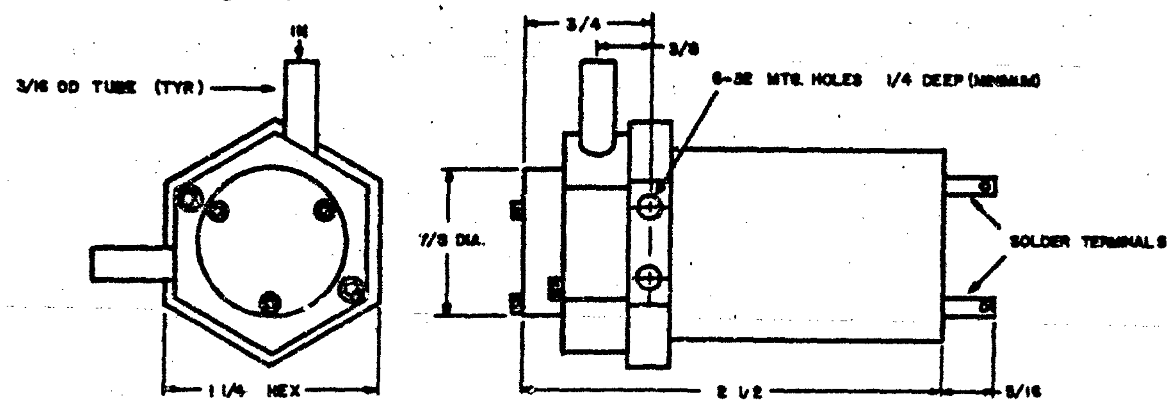
The Model 9004 Pump is designed to produce pulsation-free flow of gases at low flow rates at low static head. The pump, constructed of stainless steel and carbon, operates on DC current. Continuous or intermittent operation is featured with stable operating characteristics, with minimum maintenance, and with extremely low power consumption.



The pump is particularly well adapted to sampling of gases in battery-operated monitoring devices. At low static head, a typical pump will sample at 0.5 liters/minute with an input of 2.4 volts at 40 milliamps. A set of two standard nickel-cadmium "D" cells will operate this pump for over 100 hours.

The Model 9004 Pump can be manufactured to suit a variety of applications. The following specifications are for the standard version which has proven most successful for air sampling instrumentation. Information regarding alternate configurations can be obtained by contacting the RPC Engineering Department.

| | |
|---|---|
| Excitation Voltage (volts DC) | 3 to 12 |
| Weight (ounces) | 8 maximum |

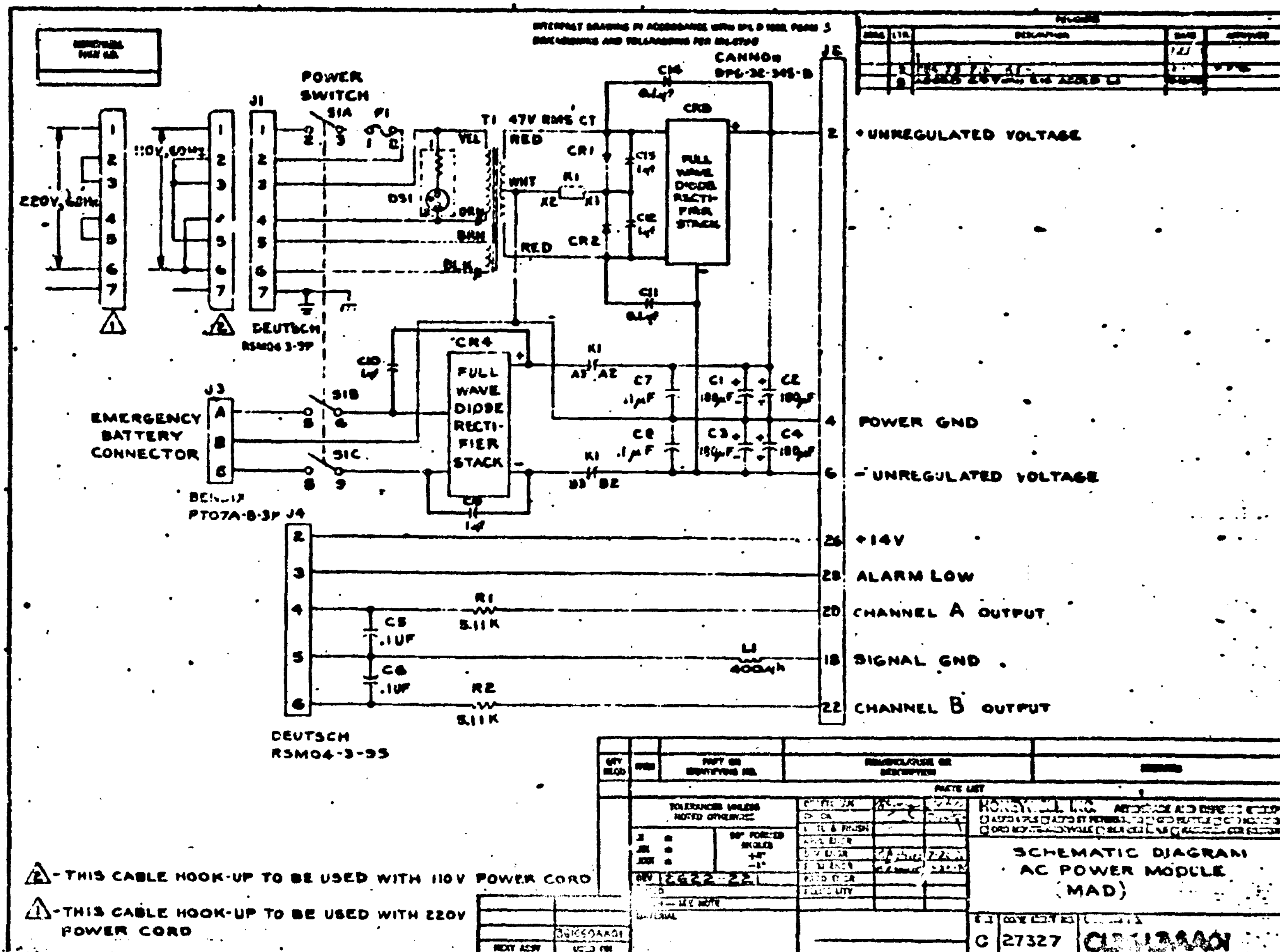


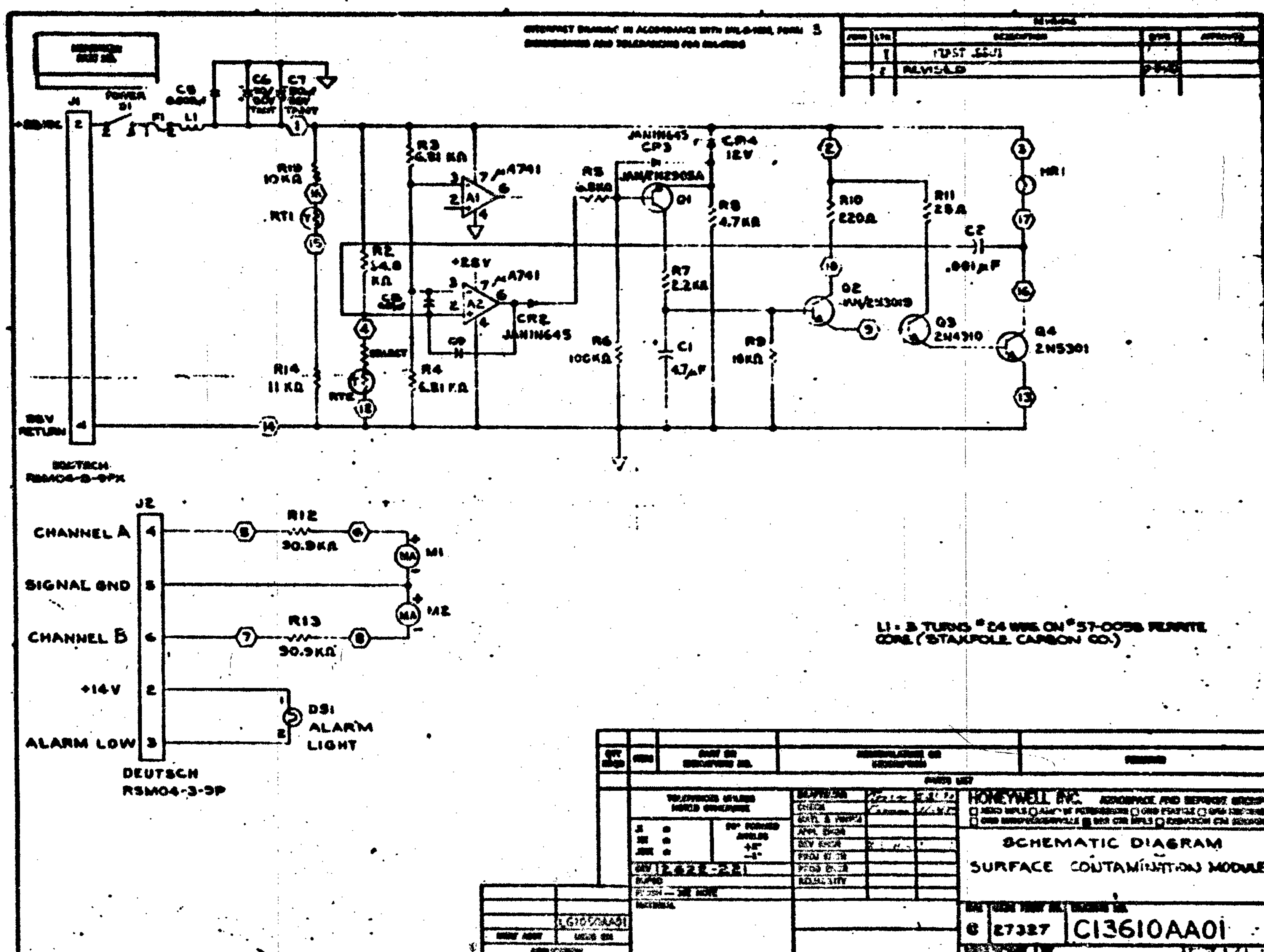

| | 3VDC | 6VDC | 12VDC |
|---|---|---|---|
| Flow (unrestricted) (liters/minute) | 1.0 | 2.0 | 4.0 |
| Static Head (no flow) (inches of $H_2O$) | 15 | 50 | 100 |
| Excitation Current (full flow) (milliamps) | 40 | 100 | 240 |
| Excitation Current (no flow) (milliamps) | 80 | 200 | 500 |

0.9 l/min at 2" Hg



RPC CORPORATION 1222 EAST GRAND AVENUE • EL SEGUNDO, CALIFORNIA 90245 • TELEPHONE: 213 / 322-0855 / 772-1191


POWER SWITCH
S1A
F1
T1 47V RMS CT
CANNON DPG-32-34S-B
J1
J2
J3
J4
CR1
CR2
CR3
CR4
FULL WAVE DIODE RECTIFIER STACK
DS1
R1
K1
C1
C2
C3
C4
C5 .1UF
C6 .1UF
C7 .1μF
C8 .1μF
C9
C10
C11
C12
C13
C14
R1 5.11K
R2 5.11K
L1 400μh
S1B
S1C
220V, 60Hz
110V, 60Hz
DEUTSCH RSM04-3-3P
EMERGENCY BATTERY CONNECTOR
BENDIX PT07A-8-3P
DEUTSCH RSM04-3-3S
+ UNREGULATED VOLTAGE
POWER GND
- UNREGULATED VOLTAGE
+14V
ALARM LOW
CHANNEL A OUTPUT
SIGNAL GND
CHANNEL B OUTPUT
RED
WHT
YEL
BRN
BLK
PARTS LIST
TOLERANCES UNLESS NOTED OTHERWISE
SCHEMATIC DIAGRAM AC POWER MODULE (MAD)
C
27327
2-THIS CABLE HOOK-UP TO BE USED WITH 110V POWER CORD
1-THIS CABLE HOOK-UP TO BE USED WITH 220V POWER CORD



CHANNEL A
SIGNAL GND
CHANNEL B
+14V
ALARM LOW
DEUTSCH
RSM04-3-9P
R12
30.9KΩ
R13
30.9KΩ
DS1
ALARM
LIGHT
J1
J2
POWER
S1
F1
L1
C6
C7
R3
6.81 KΩ
μA741
R2
R4
6.81 KΩ
R5
R6
10KΩ
R7
2.2KΩ
R8
4.7KΩ
R9
R10
220Ω
R11
C1
4.7μF
C2
.001μF
CR2
JAN1N645
CR4
12V
Q1
Q2
Q3
2N4310
Q4
2N5301
M1
M2
MR1
RT1
RT2
R14
11 KΩ
R15
10KΩ
28V
RETURN
+28V
L1 - 3 TURNS #24 WIRE ON #57-0058 FERRITE CORE (STACKPOLE CARBON CO.)
HONEYWELL INC.
SCHEMATIC DIAGRAM
SURFACE CONTAMINATION MODULE
C 27327 C13610AA01
FIRST ISSUE
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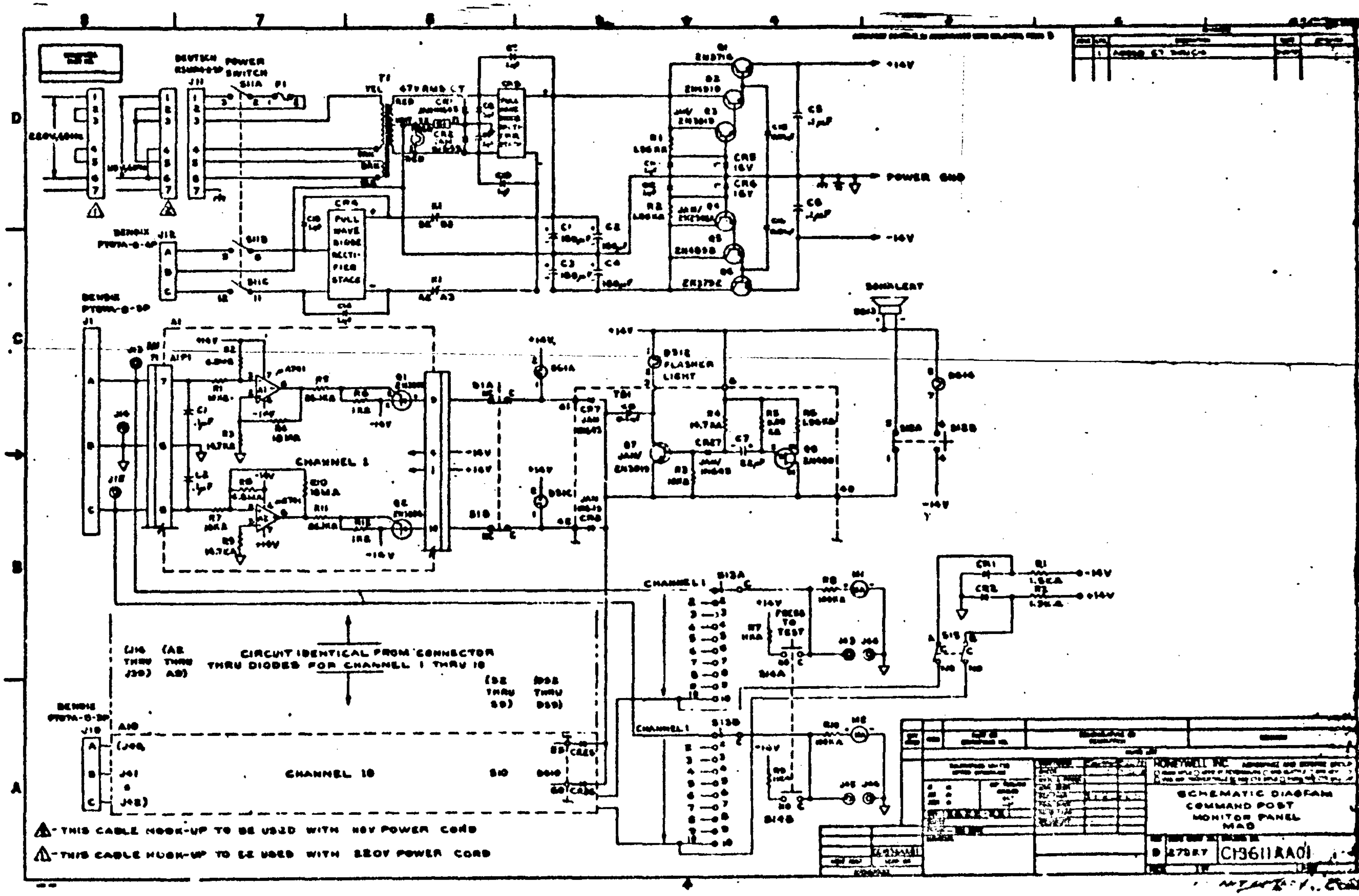
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COMMAND POST
MONITOR PANEL
MAD
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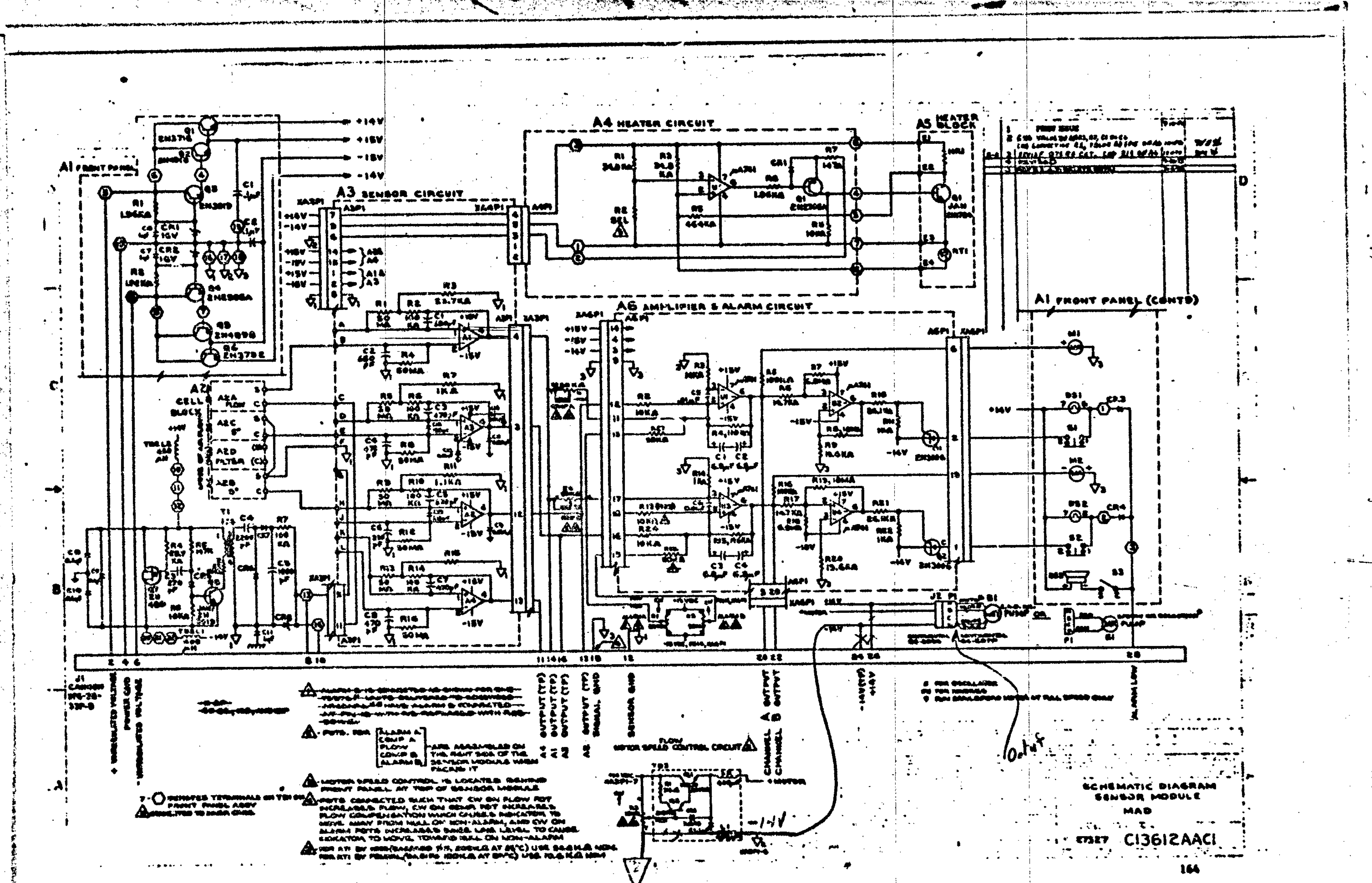
CHANNEL 1
CHANNEL 10
POWER GND
SONALERT
FLASHER LIGHT
PRESS TO TEST
POWER SWITCH
FULL WAVE DIODE RECTIFIER STAGE
THIS CABLE HOOK-UP TO BE USED WITH 115V POWER CORD
THIS CABLE HOOK-UP TO BE USED WITH 220V POWER CORD




SCHEMATIC DIAGRAM
SENSOR MODULE

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